San Lorenzo Valley Water District

Watershed Management Plan

Part I: Existing Conditions Report

Final Version

May 11, 2009

San Lorenzo Valley WATER DISTRICT

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EXECUTIVE SUMMARY

The Existing Conditions Report is Part I of the San Lorenzo Valley Water District Watershed Management Plan, which the District's Board of Directors directed staff to prepare in 2006. The Existing Conditions Report updates the District's 1985 watershed protection plan to reflect subsequent changes in the District's land ownership and service area, changes in watershed conditions, advances in watershed science, and changes in regulatory requirements. Some specific changes include:

- The 1996 Safe Drinking Water Act and the Surface Water Treatment Rule increased drinking water standards and began to emphasize the importance of source water protection.
- In 1998, the San Lorenzo River was listed as impaired under the Clean Water Act for sediment.
- In 2002, the sediment Total Maximum Daily Load (TMDL) for the San Lorenzo River was adopted by the Central Coast Regional Water Quality Control Board.
- In 2003, the Office of Administrative Law approved the San Lorenzo River sediment and nitrate TMDLs.
- In 2005, the Central Coast coho salmon was listed as endangered under the federal Endangered Species Act.
- In 2006, the District annexed both the Mañana Woods subdivision and the Felton community into its service area.
- In 2006, California Assembly Bill 32 (AB 32), also known as the "California Global Warming Solutions Act of 2006," became the first law to comprehensively limit greenhouse gas (GHG) emissions at the state level.
- In 2007, the International Panel on Climate Change published its summary report on climate change for policymakers.
- In 2008, the District acquired the Felton water system and 252 acres of watershed land in the Fall Creek watershed.
- In 2008, the District Board approved a resolution on climate change, inventoried its greenhouse gas emissions with the California Climate Action Registry, and sponsored a public forum on climate change and local water resources.
- In 2009, the District had its 2006 and 2007 greenhouse gas inventories certified by the California Climate Action Registry.

This report documents current conditions in the watershed, to the best of staff's ability, and it identifies known information gaps with regards to conditions in the watershed.

ES 1.1. About the SLV Water District

Established in 1941, the San Lorenzo Valley Water District serves approximately 7,400 connections (22,500 people) within the San Lorenzo Valley, in the Santa Cruz Mountains on the Central Coast of California. The District partners with other water agencies in the region to protect the water supply of the 138 square mile San Lorenzo River watershed. The District's mission statement reflects its interest in protecting its watershed lands:

> Our mission is to provide our customers and all future generations with reliable, safe and high quality water at an equitable price; to create and maintain outstanding customer service; to manage and protect the environmental health of the aquifers and watersheds; and, to ensure the fiscal vitality of the San Lorenzo Valley Water District (District website, 2007).

The District's three watershed management goals, defined in its initial 1985 watershed management plan were:

- To maintain and restore surface and groundwater quality consistent with state and federal regulations.
- To maintain and enhance vegetative cover, plant diversity, wildlife habitat, and natural biotic communities.
- To allow recreational uses of watershed lands consistent with a high level of environmental protection (SLVWD, 1985).

ES 1.2 Overview of District lands & water supply

The San Lorenzo River watershed is characterized by steep mountainous headwater areas, a Mediterranean climate, and remarkable biodiversity. Development, logging, mining, and water extraction have all had an impact on the health of the river. The District relies on six surface water sources in the upper watershed, primarily during the wet season, and on several ground water sources, which tap the Santa Margarita Sandstone and the Lompico aquifers, primarily in the dry season. The District owns approximately 1,800 acres serving as watershed for its surface water intakes and wells. The primary land uses that could impact surface water sources include residential development, timber production, vineyards, and recreation. The primary land uses that could impact ground water recharge areas include residential development, equestrian and motorcycle use, quarrying, and timber production. The District has four separate water systems: the Northern, the Southern, Felton, and Mañana Woods. Felton is served by surface and spring water. The Northern system is served by both surface water and groundwater. The Southern system and Mañana Woods are currently served only by groundwater.

ES 1.3 Hydrology, geomorphology & water quality

Both natural processes and human impacts have shaped the San Lorenzo River watershed. The Santa Cruz Mountains were formed and uplifted by shifts of the Pacific Plate against the North American Plate, throughout the millennia. This uplift exposed the ancient marine layer--mostly sedimentary rock--to weathering, erosion, and mass wasting. The fault lines within the watershed created three different geologic regions, with different soil types. The area's steep, rugged topography, coupled with episodic storm events give the watershed a high natural background erosion rate.

Streamflow in the river is directly related to precipitation. Ninety percent of the rainfall occurs from November through April. Averaging approximately 60 inches per year at the crest of Ben Lomond Mountain, rainfall has ranged from 22 inches in 1976-77 to 111 inches in 1982-83.

Winter streamflow increases after the soil is saturated, typically in December through March, spiking after episodic rainfall. Coastal fog also delivers some moisture to the San Lorenzo Valley, but less than other parts of the coast-line, because the high ridgeline of Ben Lomond Mountain tends to block the direct incursion of fog from the west (Singer in Swanson Hydrology & Geomorphology, 2001).

The post-settlement period after 1800 witnessed profound human impacts from logging, mining, and development. As old-growth forests were clear-cut, roads and houses were constructed, and quarries were mined, both water quality and water supply were dramatically affected. The continued use of logging roads as residential access roads created chronic sources of erosion and sedimentation. The pervasive road network, especially unpaved and poorly maintained roads, continues today as the most persistent sources of sedimentation to streams. The District has not surveyed the roads on its watershed lands, but annually inspects and maintains its road system.

The San Lorenzo River has been considered impaired under the Clean Water Act by sediment since 1998, and has since been listed as impaired for nitrates and pathogens. Upland sediment sources and a general lack of large woody debris have continued the trend of bed sedimentation. The District's surface water supply tributaries are relatively protected, but sediment and turbidity remain the primary water treatment concerns.

Groundwater levels have declined in the two primary aquifers that comprise the Santa Margarita Basin, reducing the available water supply for the District and other water agencies. Groundwater recharge to the Santa Margarita Sandstone aquifer, tapped by the District's Olympia and Quail Hollow wells, is derived primarily from percolating rainfall. The recharge area for these wells is largely rural and undeveloped. Land use in the recharge area includes a closed sand quarry, undeveloped open space including timberland, and rural residential development. The District's Quail Hollow wells are susceptible to groundwater contamination from spills, due to high permeability of soils in the recharge area and residential development.

ES 1.4 Biotic resources

The Santa Cruz Mountains is defined as a bioregion. Best known for its redwood forests, it is also home to plant communities such as sandhills and sand parklands, found nowhere else in the world. This remarkable biological diversity also characterizes the San Lorenzo River watershed. Since most District-owned lands have not been biologically surveyed, assessment of its biotic resources relies on observations of staff, consultants, and findings of local studies. Human disturbance over the last 200 years has created significant, chronic impacts to plant communities, wildlife and fisheries habitats. These impacts have, in turn, affected the natural processes that are fundamental to ecosystem function, including the hydrologic or water cycle, the carbon cycle, nutrient cycle, energy cycle, and ecological community succession.

Redwood and mixed redwood forest plant communities cover approximately 75% of the San Lorenzo River watershed's land area, including most of the District's land around its surface water sources. The District's lands have not been surveyed for vegetation, wildlife, sudden oak death or invasive exotic species.

While almost all of the old-growth forest was clear-cut in the last century, the District's lands contain stands of second growth forests that are old enough to show some old-growth characteristics, such as flat tops, snags and downed logs. Late seral-stage forests such as these provide valuable ecosystem services, including carbon sequestration, provision of clean water, and habitat for many species of mammals, birds, reptiles, amphibians, and fish.

At higher elevations, redwoods transition into mixed evergreen and chaparral plant communities, which commonly dominate the drier south-facing slopes. Other notable plant communities include riparian woodland, oak woodland, and grassland. The rare sandhills and sand parkland communities, which are found in and around the District's groundwater sources, include several endangered plant and animal species.

Sudden oak death has infected many areas of the watershed, and is present to some degree on District watershed lands. Invasive exotic plants, including French broom, eucalyptus and acacia, and exotic animal species such as feral pigs, are an acknowledged problem throughout the watershed, including the District's forest watershed lands and wellfields.

The San Lorenzo River and its estuary are inhabited by at least 25 different species of native fish. Both coho salmon and steelhead were once common and widespread throughout the coastal streams of the Pacific coast. Both species have declined; coho precipitously. In 1997, steelhead on the central coast were listed as threatened under the federal Endangered Species Act (ESA), and in 2005, coho salmon on the central coast were listed as endangered. Stream sedimentation, lack of large woody debris, water diversions, and barriers to stream passage have all contributed to these species' decline.

ES 1.5 Fire management

Fire is part of an important cycle of natural processes in forests and watersheds. Historic fire regimes of Native Americans included intentional burning. Fire suppression in more recent years has increased the chance of a major fire, which could seriously alter surface hydrology and sedimentation. No major wildfires have occurred in the watershed in the last three decades, which has increased the overall fuel load. Under the right conditions, a watershed-scale fire could result. Such a fire could impact watershed health and water quality from altered surface hydrology, increased sedimentation, chemical impacts from fire retardants, and habitat degradation. Critical fire weather is concentrated in July through October.

Drier inland areas are more prone to fire than moister coastal forests. Late seral stage redwood forests can resist the effects of all but the most intense wildfires. Redwoods are not fire dependent; that is, they can survive and regenerate without fire. Redwoods thrive in coastal areas with summer fog, which helps to lessen fire hazard.

Fire suppression is drastically altering the community structure of the rare sandhills plant communities. Invasive populations of French broom and acacia on the Olympia Wellfield have increased the risk of catastrophic fire.

The District's forested watershed lands have not been professionally assessed for fire hazard or for risk of ignition. CalFire, the state agency that manages wildfire, has rated most land in the District's service area on the west side of the San Lorenzo River as high fire hazard.

The District's watershed lands have not been specifically assessed in terms of the likely aftermath of a high intensity fire. Because elevated turbidities persist much longer in reservoirs than in streams, the District's surface water sources from local tributaries would probably have a shorter recovery time than a reservoir source, such as Loch Lomond.

ES 1.6 Cultural, historical, recreational & educational resources

The first residents of the San Lorenzo River watershed were the Ohlone Indians, who were nomadic hunters and gatherers. They managed grasslands with fire to encourage the growth of seed-bearing annuals and to facilitate hunting. After colonial settlement, from the 1860s through the 1890s, logging was the major land use in the San Lorenzo River watershed. By 1899, Boulder Creek was the fifth largest shipper of timber in the country. Old-growth stumps are found throughout the watershed.

Mineral resources of the San Lorenzo River watershed are primarily lime, limestone, sand, gravel, and crushed rock. By 1878, Santa Cruz County supplied more than one-third of the state's lime production, mostly from quarries in the Felton and Santa Cruz areas. Within the watershed, old limekilns provide historical evidence of a once thriving industry.

Tourism began as an industry in the region early in the 1900s. Historically, the tourist industry focused on the redwoods of the San Lorenzo Valley, and the beach at Santa Cruz. The first state park was Big Basin, formed in 1906. Since the early 1960s State Parks have expanded to encompass over 9,000 acres of land in the watershed, including Henry Cowell, Fall Creek, Castle Rock, and Big Basin. There are also many county and city parks.

The District currently does not actively manage any of its lands for recreational purposes. It does have an agreement with the Santa Cruz County Horseman's Association (SCCHA) for limited use of the District's Olympia property. This agreement calls for an annual joint inspection of the entire trail network, but this has not occurred in recent years. There is evidence of unauthorized off-road vehicle use on the Olympia property, as well as evidence of damage to biotic resources caused by these unauthorized activities.

The San Lorenzo Valley has many educational resources, including schools, the university, the public libraries and the Boulder Creek Historical Society. The District has supported research efforts on its lands with respect to fisheries and wildlife habitat.

ES 1.7 Local climate change assessment

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide, known as greenhouse gases (GHG), have increased markedly as a result of human activities since 1750. GHG levels now far exceed pre-industrial values determined from ice cores spanning many thousands of years. This increase is attributed to human activities, especially the burning of fossil fuels (coal, oil, natural gas) which have been locked within the earth's crust for millions of years, and the clearing and burning of forests.

Observed long-term changes in climate include altered Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones. With virtual certainty, scientists have projected for this century--for most land areas in the world--that there will be warmer and fewer cold days and nights, and warmer and more frequent hot days and nights. They also project that there will very likely be more warm spells and heat waves, more heavy precipitation events, and global mean sea level rise of 1.4 meters or more by 2100.

For California, scientists have found that a doubling of CO_2 atmospheric conditions from pre-industrial values will lead to increased temperatures of up to 4 degrees C on an annual average basis. Winters will be drier in all regions, with a slightly shorter wet season. The total amount of water in the state will decrease, water needs will increase, and the timing of water availability will be greatly perturbed.

These changes in temperature and precipitation will change vegetation patterns in watersheds and recharge areas. Increased rainfall and runoff intensity could result in more sewage overflows, and upset the basis of stormwater management plans and TMDLs.

The District has taken steps to address both the adaptation and mitigation sides of climate change. In 2008, the District Board approved a climate change resolution committing itself to meeting greenhouse gas emissions to AB 32 standards. In addition, the resolution has committed the District to addressing potential impacts of climate change in all of its planning documents.

Forests are natural sinks of carbon. There is carbon uptake into both vegetation and soils in terrestrial ecosystems. Forests absorb carbon dioxide from the atmosphere during photosynthesis, and store carbon in their biomass. Older forests store more carbon than younger forests. The declining average number of years between harvests means that less carbon is being stored in forests than in the past. While younger forests may, on average, grow at faster rates than older forests, older forests store more carbon per acre than younger ones.

The California Climate Action Registry (CCAR) is a non-profit public/private partnership that serves as a voluntary GHG registry to protect, encourage, and promote early actions to reduce GHG emissions.

California Assembly Bill 32 (AB 32), also known as the "California Global Warming Solutions Act of 2006," is the first law to comprehensively limit greenhouse gas (GHG) emissions at the state level. AB 32 was passed by Legislature, signed by the governor, and became law January 1, 2007. It establishes annual mandatory reporting of GHG emissions for significant sources and sets emission limits to cut the state's GHG emissions to 1990 levels by 2020.

The California Air Resources Board is required to incorporate the standards and protocols developed by the CCAR when developing the state's mandatory reporting program. CCAR members who have entered their carbon emissions to CCAR standards will have their data recognized and accepted by the state's future reporting program.

The San Lorenzo Valley Water District became a member of the CCAR in August 2007 and submitted its GHG emissions inventory report to CCAR in 2008.

CCAR is transitioning into the national GHG reporting nonprofit, The Climate Registry, which has adopted many of CCAR's reporting protocols.

The CCAR has also created protocols for landowners of at least 100 acres of forestland in California to provide GHG emissions accounting, reporting, and certification guidance. Qualifying entities may be eligible to receive monetary carbon credits for preserving, reforesting or conserving their forests.

LIST OF FIGURES

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CHAPTER 1: INTRODUCTION

1.0 Introduction and purpose

The San Lorenzo Valley Water District (District) is the primary water supplier to approximately 7,400 connections (22,500 people) within the unincorporated area of San Lorenzo Valley in the Santa Cruz Mountains, on the central coast of California.

The District's surface water and groundwater supplies originate entirely within the San Lorenzo River watershed area of approximately 138 square miles, as depicted in Figure 1-1. The District has a substantial stake in protecting and enhancing the health of the San Lorenzo River watershed, as reflected in the District's mission statement, adopted by the Board in June, 2000:

> Our mission is to provide our customers and all future generations with reliable, safe and high quality water at an equitable price; to create and maintain outstanding customer service; to manage and protect the environmental health of the aquifers and watersheds; and, to ensure the fiscal vitality of the San Lorenzo Valley Water District.

The District has worked cooperatively with its community and other public agencies in pursuing its mission.

The purpose of this document is to provide information to assist the District in enhancing and protecting water quality, throughout the watershed, but especially within watershed lands owned by the District, and within the District's service area where the District exercises the most control. The document is intended as a reference to be used by District directors, staff, the public, contractors, educators, scientists, and other agencies.

1.1. Background

After the State Legislature declared the San Lorenzo River part of the State Protected Waterways Program in 1976, local residents advocated for public protection of the natural, social and economic values of the San Lorenzo River watershed. In response, the County of Santa Cruz and the State Department of Fish and Game, with input from local citizens, produced the first San Lorenzo River Watershed Management Plan, in 1979 (County of Santa Cruz, 1979). The agencies issued a draft update to this plan in 2001 (County of Santa Cruz, 2001).

In 1985, the District's Board of Directors adopted the District's first Watershed Protection Plan (San Lorenzo Valley Water District, 1985).

In 2005, the District Board of Directors directed staff to prepare a new management plan to reassess the District's management goals and policies, so that they to reflect changes that have occurred since 1985 in the following areas:

- District land ownership and service area
- Watershed conditions
- Advances in scientific research in watershed science and ecosystem management
- New federal and state regulatory requirements

Since 1985, the District has bought and sold watershed lands, has annexed territory into its service area, and has endured major natural disturbances.

Since 1985, some improvements in river water quality have been made, but development in the watershed has increased, and ground water aquifers have dropped. Invasive exotic species continue to present a problem for land managers.

Since 1985, research in forest ecology, watershed science and aquatic biology has produced new models of ecosystem management and adaptive management. Local studies have provided new information about watershed conditions in the San Lorenzo River watershed, in terms of water quality, water supply, fisheries habitat, and groundwater aquifers.

Since 1985, new Federal and state programs and standards under the Safe Drinking Water Act (Safe Drinking Water Act Amendments, 1996) and the Surface Water Treatment Rule (SWTR, 1998) have increased drinking water standards, and placed new emphasis on source water protection.

Since 1985, two key salmonid species have been federally listed under the Endangered Species Act. Steelhead are listed as threatened, and coho salmon are listed as endangered. Recovery of these species is mandated by the Endangered Species Act (NMFS, 2005).

Since 1985, the San Lorenzo River and tributaries have been listed by the Central Coast Regional Water Quality Control Board as an impaired waterway due to sediment, nutrients and pathogens affecting drinking water, fisheries, and recreational beneficial uses under section 303(d) of the federal Clean Water Act. The State and Regional Water Quality Control Boards and the EPA adopted a Total Maximum Daily Load (TMDL) for sediment in for the San Lorenzo River and its tributaries (CCRWQCB, 2002). The TMDL is required to include a source analysis, numeric targets, linkage analysis, TMDLs, load allocations, an implementation plan, and a monitoring plan. The sediment TMDL and the nitrate TMDL were approved by the Office of Adminstrative Law in 2003. The pathogen TMDL is scheduled for consideration in 2008.

1.2 The District's partnerships in watershed protection

The District has a long history of working cooperatively with other agencies to protect the San Lorenzo River watershed. District staff was part of the Technical Advisory Committee to the 1979 San Lorenzo River Watershed Management Plan, which was written by the County. The District has actively participated in the 1996, 2001, and 2006 San Lorenzo River watershed sanitary surveys, coordinated by the City of Santa Cruz. The District has sponsored and co-sponsored salmonid studies of the San Lorenzo River since 1994, partnering at different times with the County, the City of Santa Cruz, and the Lompico County Water District. In addition, the District completed source water assessments for each of its water sources, as required by the State Department of Health Services, Drinking Water Program.

In 2003, the District established an Education Program Advisory Commission to advise the Board of Directors in awarding education program grants and scholarships. Since then, the District has budgeted up to $17,500 per year to fund grants of up to $2,500 for educational, restoration, and resource conservation projects, which enhance the understanding of the San Lorenzo River watershed or improve the watershed's environmental health. Some of the non-profit organizations that have been awarded grants include the Sandhills Alliance for Natural

Diversity, the Monterey Bay Master Gardeners, the Santa Cruz County Resource Conservation District, the Mount Hermon Outdoor Science School, as well as local public schools.

In 2008, the District initiated and co-sponsored a local climate change working group composed of other local public water agencies to address potential impacts and mitigations of climate change. In May 2008, this inter-agency group sponsored a public forum entitled,"Tools for Addressing Climate Change and Local Water Resources," featuring presentations from acknowledged experts in water resources and climate change.

The District and California State Parks have partnered successfully in the past in watershed management. Until 2001, the District owned the 1,370 acre Waterman Gap property at the headwaters of the San Lorenzo River at the southern boundary of Castle Rock State Park. The two agencies worked out land use agreements and easements to provide for public access, recreation, and appropriate watershed management (California State Park and Recreation Commission, 2000). The District sold the Waterman Gap property to Sempervirens Fund in 2000, and the property has since become part of Castle Rock State Park.

The District has long recognized the value of stakeholder involvement in the watershed planning process. The planning process occurs both at regular Board meetings, and at the Board's Environmental Committee meetings. All of these meetings are open to the public, and are noticed on the District's website.

1.3 Scope of document

The scope of this document is defined by its goals, and its geographic and temporal limits.

Geographically, the scope of the document includes the entire San Lorenzo River watershed, with an emphasis on the subwatersheds that supply the District's water. The entire watershed is included for several reasons. First, the District is one of many water purveyors that depend on the watershed; the District works cooperatively to protect the watershed's resources, including water quality and water supply, and fisheries. Second, because there is little existing survey data that address natural resources on District-owned lands, the District must draw from studies that address a larger watershed scale, as well as studies that focus on nearby subwatersheds. These studies may be used to extrapolate information to District-owned lands, while the District plans and prioritizes further studies on its own lands.

Temporally, the scope of this document is ten years. The US EPA (2005) advises that watershed studies be updated at least every ten years. During this period, watershed planners should make a reasonable effort to identify significant pollutant sources, specify the management measures that will most effectively address those sources, and broadly estimate the expected load reductions that will result.

On the other hand, US EPA (2005) recognizes that the information available during the planning stage may be limited. Therefore, preliminary information may need to be updated as it becomes available, and prescribed management measures may need to be assessed for their effectiveness more frequently. This principle of adaptive management ensures that management measures can proceed even though information in the watershed plan may be imperfect and require modification over time, as better information becomes available.

1.4 How to use this document

This document is divided into two parts:

- Part I: Existing Conditions Report
- Part II: District Goals, Objectives and Management Strategies

Part I: Existing conditions

Part I provides the contextual background for management decisions, by describing current watershed conditions, tracing historic and current impacts, and describing efforts to address these impacts. Part I generally describes the San Lorenzo River watershed. It begins by providing a setting for the watershed in terms of the region's climate and geography. It examines the area's geology, soils, as well as its geomorphology and hydrology. Next, it describes the biotic resources of the watershed, and the ecosystem functions and natural services that these resources provide. It summarizes the area's fire ecology, and provides an overview of the watershed's historical, cultural, and recreational resources. Finally, Part I summarizes advances in scientific research in watershed science and ecosystem management, and discusses potential approaches of assessing the local impacts of climate change on the watershed's resources.

Climate change is expected to have various impacts on the existing conditions of the District's resources resulting from temperature increases and more extreme weather patterns at the local scale. Each chapter briefly introduces these potential impacts to watershed resources.

Part I draws heavily on research at the watershed scale, in part drawn from other local agency plans, which synthesize research. The report focuses, as much as possible, on the District's land ownership and the subwatersheds and aquifers that supply the District's water.

The public and peer-review of Part I, the Administrative Draft of the Existing Conditions Report, identified information gaps which are flagged within the text of this document with the icon to the left. Policies are in place in Part II to prioritize filling these information gaps.

Part II: District goals, objectives, and management strategies

Part II affirms the District's approach of ecosystem management, defines goals, objectives and policies designed to assist the District in realizing its mission, prioritizes studies for filling the data gaps identified in Part I, and identifies indicators to measure the progress of management strategies. Part II is intended as a reference for the District directors and staff to design projects that meet the agency's management goals, and to measure the success of such projects in meeting those goals.

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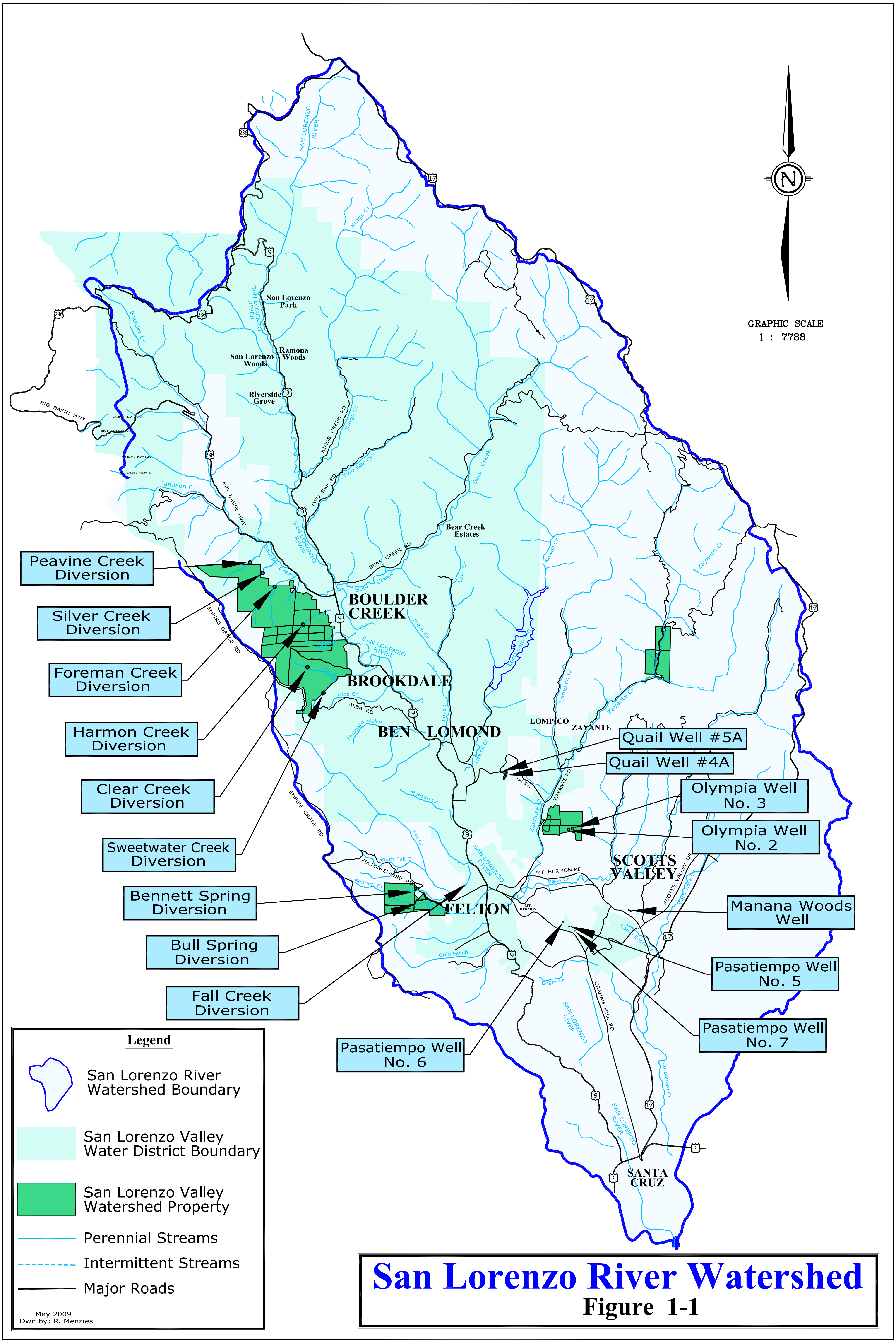


San Lorenzo River Watershed

Figure 1-1

CHAPTER 2: OVERVIEW OF DISTRICT LANDS & WATER SUPPLY

2.0 Introduction

This chapter begins by providing a regional overview of the Santa Cruz Mountains, followed by a general description of the San Lorenzo River watershed. The chapter then provides a more detailed description of District-owned watershed lands, and an overview of the District's surface and ground water supplies.

It should be noted while reading this overview that significant impacts from climate change are likely occurring throughout the regional, watershed, and landscape scales. Locally, predicted climate change impacts include temperature rise, increased droughts and more intense rainfall events. Chapter 7: Local Climate Change Assessment discusses some of the scientific research and policy recommendation to date, especially in regard to water resources.

2.1 Regional setting: The Santa Cruz Mountains

The Santa Cruz Mountains covers an area of 3,592 square kilometers (1,387 square miles) on the central coast. The region is bounded on the north by the Golden Gate, on the east by San Francisco Bay and the Santa Clara Valley, on the south by the Pajaro River and on the west by the Pacific Ocean. The Santa Cruz Mountains is defined as a bioregion, as shown in Figure 2.1. It is acknowledged as one of the more biologically diverse areas in California.

Figure 2.1. The Santa Cruz Mountains Bioregion

Source: Santa Cruz Bioregional Council, 2007

According to the Santa Cruz Mountains Bioregional Council (2007):

"The region is essentially one of heavily populated lowlands surrounding a core of forested uplands, with small to large pockets of everything from salt marsh to chaparral intermixed. It is rich in endemics and many other natural features of special interest, some of whose past and current distributions are well known, others hardly at all."

The region's Mediterranean climate is characterized by relatively cool, dry summers and moderate-to-heavy rainfall in the winter months. Approximately 90 percent of the annual rainfall in the region occurs between November and April. The region is known for its coastal redwoods, which depend on coastal fog.

Streams flowing from the Santa Cruz Mountains drain into the Monterey Bay or the Pacific Ocean. The Monterey Bay was declared a National Marine Sanctuary in 1992.

The Monterey Bay Marine Sanctuary is the nation's largest marine sanctuary, encompassing over 5,300 square miles along the Central California coast. The sanctuary ranges from Cambria, San Luis Obispo County northward to Rocky Point in Marin County. The sanctuary contains some of the world's largest underwater canyons, important habitats, and some of the most productive and diverse deep ocean waters and floors in the world.

2.2 The San Lorenzo River watershed

The District's surface water and groundwater supplies originate entirely within the San Lorenzo River watershed, depicted in Figure 1.1, is one of the major watersheds in the Santa Cruz Mountains.

2.2.1 Topography

Elevation ranges in the watershed from the 3,214 feet at the summit of Castle Rock Peak, down to sea level at the mouth of the river. With its headwaters at an elevation of approximately 2,900 feet, the San Lorenzo River drops 2,000 feet in the first 3 miles (CCRWQCB, 2002). Small, steep tributaries feed the river from the west at Ben Lomond Mountain, while wider, more gently sloping tributaries feed the river from the east and northeast. The San Lorenzo River flows to the north end of the Monterey Bay. Refer to Chapter 3, Hydrology, Geomorphology, and Water Quality for more information about the topography of the watershed.

2.2.2 Climate

Annual rainfall varies between 15 inches to more than 100 inches throughout the watershed, depending upon location and year. Ben Lomond Mountain, source of the District's surface water, averages near the high end of the range. Rainfall averages approximately 46 inches per year in the watershed above Big Trees, but less than that in the remainder of the watershed, down to the beach. Six to ten consecutive days of rainfall is not unusual for the San Lorenzo River watershed (Swanson Hydrology, 2001). Coastal fog is an important part of the summer climate, creeping into inland valleys at night and in mornings.

Average daily temperatures vary throughout the watershed, generally ranging from 30^{o} F and 90^{o} F. The lowest temperature recorded at Ben Lomond Station was 15^{o} F, on December 23, 1977, and again on December 22, 1980. The highest temperature recorded at Ben Lomond Station since 1972 was 112^{o} F in October 1996. Refer to Chapter 3: Hydrology, Geomorphology, and Water Quality for more information about the watershed's climate. Refer to Chapter 7: Local Climate Change Assessment for more information about the probable impacts of climate change on the San Lorenzo River watershed.

2.2.3 Biodiversity

The San Lorenzo River watershed supports a wide variety of natural plant communities, which in turn support a diverse range of wildlife species. Plant communities include redwood forests, chaparral, the rare sandhills, grassland, oak woodland and riparian woodland. Many of these plant communities can be found on District-owned lands. Refer to Chapter 4, Biotic Resources for more information about the biodiversity of the watershed.

Approximately 26 miles of the San Lorenzo River, and at least nine of its major tributaries, support steelhead (*Oncorhynchus mykiss*). Historically, the San Lorenzo River supported the largest coho salmon and steelhead fishery south of San Francisco Bay, and the fourth largest steelhead fishery in the State of California (County of Santa Cruz, 2001). Coho salmon and steelhead of the San Lorenzo River are listed as endangered and threatened, respectively, under the federal Endangered Species Act. Coho salmon had not been recorded in the watershed since the early 1980s (Smith, 1982), until 2005, when at least a dozen adult coho were observed at the city of Santa Cruz Felton diversion fish ladder. Refer to "Appendix A: Fisheries" for more information about steelhead and coho salmon in the San Lorenzo River watershed.

2.2.4 Geology and soils

The tectonic compression of the earth's crust that originally produced the Santa Cruz Mountains continues to shape the region, the San Lorenzo River watershed, and the District's watershed lands. The San Andreas Fault runs parallel to the northeastern boundary of the watershed. Along this fault, two major tectonic plates meet: the Pacific Plate to the west and the North American Plate to the east. Throughout geologic history, major events along this plate boundary have helped create the unique geology and topography of the San Lorenzo River watershed. The watershed itself is divided by two faults--the Zayante and the Ben Lomond faults--into three areas of distinct geology, topography, soil and groundwater characteristics. The Zayante Fault divides the watershed in half, running approximately east-west. The Ben Lomond Fault runs south to north along the San Lorenzo River until it meets the Zayante Fault. Refer to Chapter 3, Hydrology, Geomorphology, and Water Quality for more information about the geology and soils of the watershed.

2.2.5 Human uses in the San Lorenzo River watershed

This section describes the prominent human uses throughout the San Lorenzo River watershed, including development, timber, mining, water extraction, farming and ranching, recreation and tourism, and open space.

2.2.5.a Development

The watershed is home to approximately 41,000 residents inhabiting 17,174 developed parcels, outside of the City of Santa Cruz (County of Santa Cruz, 2001). Approximately 3,150 of the developed parcels are within the City of Scotts Valley (County of Santa Cruz, 2001).

The County has influenced the quality and rate of development through planning, zoning ordinances, and regulations. The result has been that the San Lorenzo River watershed retains many of its aesthetic characteristics and viewsheds.

The San Lorenzo Valley was sparsely inhabited and dominated by summer homes through the 1950s. Since then, houses within the watershed have been converted to permanent residences and some 3,300 new units were built by the 1970s (County of Santa Cruz, 2001). The County (2001) reports that, "Growth rates of over 30% occurred in Bear Creek, Upper Zayante, Bean Creek, and Branciforte." Scotts Valley also experienced an increase in development of 80% from 1980 to 2000 including large industrial complexes (County of Santa Cruz, 2001). According to the Santa Cruz County Draft Watershed Management Plan (2001):

> The overall growth rate in the watershed outside Scotts Valley was 17%. In the 1990s, growth in Scotts Valley was greater than in the remainder of the unincorporated watershed. High rates of development in the Scotts Valley area

resulted in erosion of sandy areas, paving of groundwater recharge areas, and increased pumping of groundwater."

The rate of development has slowed more recently. Early development in the watershed filled most of the flatter areas and lined most creeks, replacing valuable riparian habitat and damaging the riparian ecosystem before environmental regulations were in place. Much recent development has been in more remote, steeper areas of the watershed. Development increased the extensive road network initiated by historical logging. Roads throughout the watershed are today considered a primary contributor to erosion and sedimentation of streams (Ricker and Butler, 1979; Hecht and Kittleson, 1998; Swanson Hydrology, 2001; CCRWQCB, 2002; Alley et al., 2004). To begin to address some of the problems caused by poorly constructed and maintained roads throughout the watershed, Santa Cruz County, the Central Coast Regional Water Quality Control Board and the Santa Cruz Resource Conservation District have initiated several grant-based restoration and repair programs.

Development and conversion of summer homes to permanent residences also contributed to erosion, stream sedimentation, reduced streamflow and groundwater recharge, increased polluted-urban runoff, and failing septic systems.

The US Geological Survey (1995) reported that, generally, development within a basin reduces recharge, because significant precipitation falls on impervious surfaces such as streets and roofs, and is routed directly to surface drains. Generally, increased runoff rates from impervious surfaces result in decreased groundwater recharge, which in turn reduces water supply from wells and stream baseflows that are fed by groundwater (Dunne and Leopold, 1978).

In the Quail Hollow, Olympia and Mission Springs areas of the San Lorenzo Valley, a 1979 county study found that total runoff had increased from about 6 percent to 10 percent, resulting in an 11 percent reduction recharge, due to development in the area to that date (County of Santa Cruz, 1979.

However, natural recharge rates can be maintained or even exceeded in developed areas, where household waste water is disposed of in septic systems. The USGS demonstrated this phenomenon with hydrologic modeling (US Geological Survey, 1995). Because the San Lorenzo Valley relies on septic systems rather than a centralized sewer system, much of the water that is pumped out the river and from aquifers eventually finds its way back into the stream system (County of Santa Cruz, 1979). The cities of Santa Cruz and Scotts Valley, on the other hand, have sewer systems, which channel treated wastewater directly to the bay (Alley et al., 2004). The Scotts Valley Water District (SVWD) operates a 625,000-gallon recycled water storage tank, a recycled water booster pump station, and six miles of recycled water distribution mains to supply irrigation water to its landscaping customers (SVWD website, 2007). Recycling of wastewater both reduces pumping from an overdrafted aquifer, and reduces the amount of wastewater that is channeled directly to the bay.

2.2.5.b Timber

Historically, timber resources were the foundation of industry in the San Lorenzo River watershed (Camp, Dresser & McKee, 1996). From the late 1800s through the early 1900s clear-cut logging impacted most of the watershed, altering the natural forest ecology and introducing a pervasive road network, which remains the principal impact in the watershed today (Balance Hydrologics, 1998; Swanson Hydrology and Geomorphology, 2001; Alley et al., 2004). Small tributaries were dammed for mills to transport logs (Alley et al., 2004). By 1880, 50 logging mills were operating in the Santa Cruz Mountains (Greenlee and Langenheim, 1990). Entire hillsides were clear-cut and burned to facilitate the removal of the old growth logs. The majority of the watershed was logged in this manner.

Large scale clear-cutting in the region was disallowed by the State Forest Practice Rules several decades ago. Today, only one local sawmill remains, but much of the locally harvested timber is trucked and processed outside the county. Small, scattered patches of old-growth trees are found throughout the watershed, but the only significant stands of old-growth redwoods and Douglas fir lie within State Park lands. Forests that were clear-cut have re-grown to what is known as second-growth. The timber industry has steadily logged these second-growth forests under single-tree selection logging. Some maturing second-growth forests have attained old-growth characteristics, though the trees have not yet approached the size of ancient redwoods, such as those found in Big Basin State Park. The disappearance of most of the old-growth forest has compromised the functional characteristics of the forest ecosystem, resulting in increased susceptibility to catastrophic wildfire, and a loss of habitat characteristics necessary for native species, such as the federally threatened marbled murrelet (Singer, 2007).

The volume of commercial timber harvested in the watershed fluctuates with the market price of timber. Nearly half of the San Lorenzo River watershed was zoned for commercial timber production until 1999 (Camp, Dresser & McKee, 1996). Timber harvests were common throughout the watershed on residential parcels between five and 40 acres. Due to increasing neighborhood conflicts and failure of the state Board of Forestry to adopt the county's proposed rule package in 1998 and 1999, the county board of supervisors in 2000 limited commercial logging primarily to parcels zoned specifically for timber production (TP). In 2007, the county changed the minimum parcel size for rezoning to TPZ from 5 acres to 40 acres. Only a few private companies in the county, including Redwood Empire, Red Tree, Cemex, and Big Creek Lumber own more than 2,500 acres of forest land zoned TPZ (Camp, Dresser & McKee, 1996). For more information about logging regulation in the county, see Appendix B, History of Logging Regulation in Santa Cruz County.

2.2.5.c Mining

Many "limestone" mines on Ben Lomond Mountain produced lime for cement, to rebuild San Francisco after the 1906 earthquake. Much of the early logging was done to fuel the lime kilns scattered across Ben Lomond Mountain. Sand and gravel quarrying of the Santa Margarita Sandstone formations has occurred within much of the eastern part of the watershed.

The San Lorenzo River watershed contains several closed sand pit mines and many closed historic limestone quarries. Active quarries include granite gravel and rock mine in Felton and one active sand quarry in the sand hills area. This quarry is the only one in the area that harvests sand fine enough for the production of glass. Two other sand quarries have closed and are in the process of completing reclamation.

The San Lorenzo Valley and North Coast Watersheds Sanitary Survey (Camp, Dresser & McKee, 1996) describes mining in a regulatory sense:

The quarries are regulated under the Surface Mining and Reclamation Act (SMARA) and by the County Mining Ordinance. The County Mining Ordinance requires that the application package be submitted to the water purveyor in the drainage area of the quarry. The County inspects the quarries four times each year and the State inspects annually. The County conducts an extensive review each five years. At that time, the County Planning Commission can impose conditions on the quarry as part of the Certificate of Compliance. Mining adjacent to riparian corridors must be conducted in accordance with the Riparian Corridor and Wetlands Protection ordinance. The Regional Board issues NPDES permits that set limits on contaminants that can be discharged to surface waters from quarries. Surface discharges of both active and inactive mines to receiving streams are regulated by the Regional Board under the Waste Discharge Requirement permit program. Mines typically meet these requirements by various best management practices (BMPs).

2.2.5.d Water extraction

All of the residents of the watershed receive their water from either ground or surface water sources within the watershed. The City of Santa Cruz Water Department obtains approximately 65% of its water from the San Lorenzo River (Johnson, 2008 *in progress*). San Lorenzo Valley Water District obtains approximately 50% of its water from tributaries of the river.

Water diversions and impoundments were developed soon after settlement of the watershed for private and industrial use, and were sought after to supply the growing City of Santa Cruz. Many small flashboard dams scattered along different streams of the watershed were used by camps, summer homes, or communities to create swimming areas during the summer months. Few of these dams still operate today, but many of the structures or remnants of them still exist.

Adequate streamflow is necessary to remove deleterious sediments. Adequate streamflow is crucial to recruit and maintain beneficial gravels, cobbles, boulders and large instream wood. All aquatic organisms, from insects to steelhead and coho salmon, rely on these habitat features for cover, migration and food.

Today, the health of the San Lorenzo River is significantly affected by the volume of water diverted for human use. Reductions in streamflow caused by these diversions reduce the quantity and quality of aquatic habitat. Inadequate stream flow impacts habitat area, water depth, water velocity, water temperature, dissolved oxygen, escape cover, and surface turbulence (which oxygenates water, and provides habitat).

Diversions and wells are found throughout the watershed. The largest water users are the City of Santa Cruz, the San Lorenzo Valley Water District, the Scotts Valley Water District, and Big Basin Water Company.

District's water diversions from tributaries to Boulder Creek and from tributaries to the mainstem have a significant, yet undefined, impact on the downstream aquatic ecosystem. The same is true for the Felton diversion dam on the mainstem and the Loch Lomond dam on Newell Creek, which are operated by City of Santa Cruz. For more information about the potential impacts of the District's water diversions, refer to Chapter 4: Biotic Resources.

A smaller diversion dam on Lompico Creek serves the Lompico County Water District. Other smaller dams include the Ben Lomond dam and the Boulder Creek Recreation District dam on the mainstem of the San Lorenzo River.

2.2.5.e Farming and ranching

Horses are kept in most sub-basins and drainages within the San Lorenzo watershed, often close to streams. There are several large commercial equestrian facilities, and many residences throughout the watershed have one or two horses. Many trails are used by equestrians throughout the watershed. Only four head of cattle were identified in the San Lorenzo watershed during the field survey for the San Lorenzo and North Coast Watersheds Sanitary Survey (1996). Due to soils and the general steepness of the watershed, agriculture is limited to scattered small Christmas tree farms, vineyards, orchards, nurseries, and small home-style farms.

2.2.5.f Recreation and tourism

Recreation has always been popular within the San Lorenzo River watershed. When a majority of the watershed was used for summer homes, creeks were commonly dammed for swimming pools. A few of the larger and some private swimming areas still remain today. Locals have always enjoyed hiking throughout the watershed. The California Department of Parks and Recreation owns and manages about 9,000 acres (Camp, Dresser & McKee, 1996) of public parks within the watershed, as shown in Figure 2.2. Historically, sport fishing has been economically important to the San Lorenzo River watershed. The San Lorenzo River was for years the largest steelhead fishery south of San Francisco (CCRWQCB 2002), and remained popular for trout fishing into the 1970s (Johansen, 1975). Both local residents and tourists continue to be attracted to the watershed's recreational opportunities. Trail use by hikers, runners, bikers, and equestrians is very popular, both on and off legal trails. Big Basin State Park has one of the highest annual uses within the State Park System.

According to the San Lorenzo River Watershed Management Plan (1979):

> Recreation patterns in the watershed have changed in recent years. Initially the users of recreational resources in the Watershed were out-of-County tourists and summer residents. Today, because of an increasing tendency toward year-round residency, younger families, and day-trip tourism, many recreationists are local residents. As the population in the Watershed continues to increase, so will the recreational needs of residents. In some cases, these needs are identical with the needs of regional recreationists and can be met jointly. In other cases, resident recreational needs are distinct and require separate facilities. Some good examples of resident recreational needs are local parks that provide playgrounds for children and sports playing fields for older children and adults. Local recreation needs of this sort are not being adequately met (as cited in the District's Watershed Protection Plan, 1985).

Development of recreational facilities in the watershed has not kept pace with residential and commercial development. However, it should be noted that the region's environmental constraints and scarcity of available flat land limit the areas that could be developed as parks. For more information about recreational resources, refer to Chapter 6, Cultural, Historic, Recreational, and Educational Resources.

2.2.5.g Open space

Much of the San Lorenzo Valley is still held in large tracts of public open space land, as shown in Figure 2-2. The District owns one contiguous piece of land of approximately 1,620 acres for water supply and watershed protection on Ben Lomond Mountain, 252 acres in the Felton/Fall Creek watershed, and another 325 acres in the Zayante Creek area. The City of Santa Cruz owns 3,880 acres of watershed land, including approximately 2,760 acres around Loch Lomond, and 880 acres near Zayante Creek (Swanson Hydrology & Geomorphology, 2001). State Parks owns tracts of open space land including Henry Cowell, Fall Creek, Big Basin, and Castle Rock State Parks. State Parks recently acquired the Waterman Gap property, which is now part of Castle Rock State Park. This 1,340 acre parcel, previously owned by the District, was sold to Sempervirens Fund to facilitate its eventual transfer to State Parks. Unfortunately, due to severe budget problems, State Parks has not been able to manage many of its holdings to the standards that it once did.

Figure 2.2 Protected areas within the San Lorenzo River watershed.

(11 x 17 color fold-out)

2.3 Overview of the District's land, water supply, and distribution system

The District's surface water supply flows primarily from creeks on the western side of the watershed. Together, these creeks, which are tributaries to the San Lorenzo River, provide approximately half of the District's total water supply. The District's groundwater sources come primarily from the Santa Margarita Sandstone and Lompico Sandstone formations, on the eastern side of the watershed. The District has a substantial stake in protecting and enhancing the health of the San Lorenzo River watershed.

The District currently operates four standalone water systems with separate water supplies: The Northern System, the Southern System, the Mañana Woods System and the Felton System. Together, these four water systems serve approximately7,400 connections (22,500 people). The Northern System serves the unincorporated communities of Boulder Creek, Brookdale, Ben Lomond, Zayante and parts of Felton. The Southern System and the Mañana Woods System each serve a portion of the Scotts Valley area. The Felton System serves the community of Felton.

The Northern System is supplied by both surface water and groundwater sources (approximately 57% surface water). It relies primarily on surface water during the wet season and on groundwater during the dry season. The Southern System and the Mañana Woods system rely solely on groundwater. The District has begun planning an inter-tie between the Northern and the Southern systems that would enable the two water supplies to be shared. The Felton water system relies completely on surface water.

Prior to the District's acquisition of the Mañana Woods system in 2006 and the Felton System in 2008, the average water production from 2000 – 2004 of the Northern and Southern Systems together was 1.9 million gallons per day, with the Northern System supplying approximately 80 percent of the District's water use (Johnson, 2005). The District has not yet completed estimations of current production data including all four systems.

Table 2.1 Connections, population served and type of supply of the District's four standalone water systems

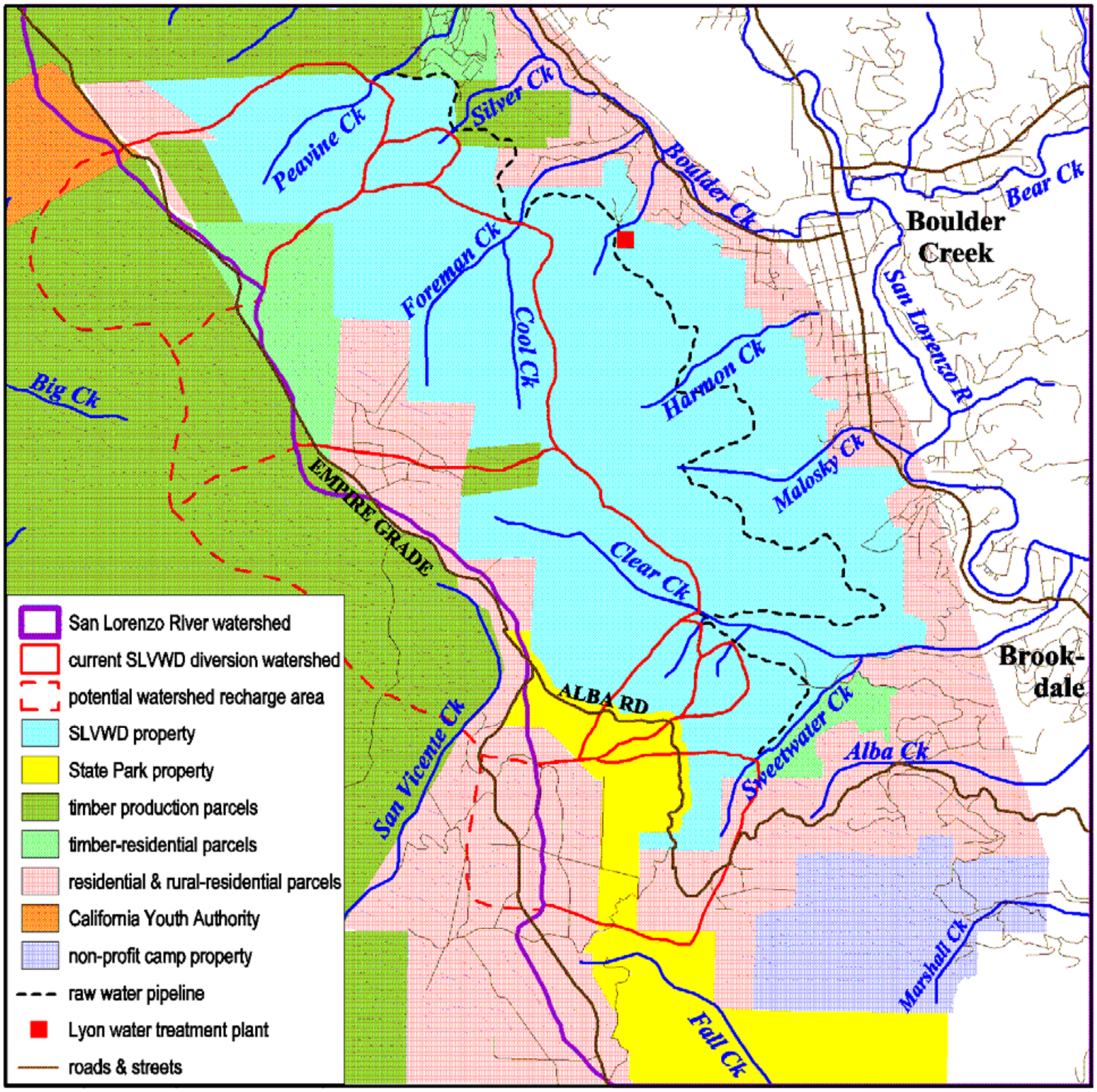
Service area	Service connections	Approximate population served	Type of supply
Northern	5,300	16,500	Ground and surface
Southern	670	2,200	Ground
Mañana Woods	113	300	Ground
Felton	1,300	3,500	Surface
Total	7,383	22,500	

2.3.1 District watershed lands

As shown in Figure 1-1, the District owns approximately 252 acres in the Fall Creek watershed land that supply the Felton water system, and approximately 1,623 acres of watershed land, in one continuous piece on Ben Lomond Mountain that supply surface water to other parts of the

San Lorenzo Valley. The District's Ben Lomond watershed lands partially encompass the District's water supply streams, which are tributaries of the San Lorenzo River: Clear Creek, Sweetwater Creek, Peavine Creek, Foreman Creek and Silver Creek. Figure 2.3 shows the primary land uses in the vicinity of the District's surface water sources. These lands are typically rugged, steep, and forested, as shown in Figure 2.4. District water intakes are located near the headwaters of these creeks. Generally, the land is mountainous, and prone to landslides. The land supports wildlife, including deer and feral pigs. The soils are predominately sandy loams, and the streams receive significant groundwater recharge from the headwaters areas surrounding them. Rainfall averages 58-60 inches per year (Johnson, 2005).

Figure 2.3. Primary land uses in the vicinity of the District's surface water sources.



Source: Johnson, 2007.

2.3.1.a Foreman Creek

Foreman Creek has a total area of 580 acres upstream of its confluence with Boulder Creek, northwest of the community of Boulder Creek. The District diverts from an intake at elevation 927 feet above mean sea level. Foreman Creek has an eastern branch about 3,000 ft long upstream of the diversion. The mainstem above the intake is 3,800 ft. long. Flows diverted from Foreman Creek are conveyed to the District water treatment plant through about 0.5 miles of pipeline. Baseflows may be augmented by groundwater recharged within a roughly 120 acre area immediately west of the watershed divide along the crest of Ben Lomond Mountain (Johnson, 2005). The District owns about 55 percent (approximately 265 acres) of the watershed upstream of the intake. There are 30 - 40 septic systems located in the Foreman Creek watershed.

Figure 2.4. District-owned watershed land is typically forested, rugged, and steep.

Herbert, 2006

The District surface water intakes are located high in the watershed, which is relatively undisturbed.

2.3.1.b Peavine Creek

Peavine Creek has a total area of 293 acres upstream of its confluence with Boulder Creek, northwest of the community of Boulder Creek. The District diverts from an intake at elevation 1,264 feet above mean sea level. The mapped length of Peavine Creek upstream of the diversion is approximately 3,100 feet. (In the past, when the District diverted water from Silver Creek, it was combined with flows from Peavine Creek.) Flows are now diverted solely from Peavine

Creek and conveyed to the District water treatment plant through about 1.4 miles of pipeline. Baseflows may be augmented by groundwater recharged within a roughly 180 acre area immediately west of the watershed divide along the crest of Ben Lomond Mountain (Johnson, 2005). The District owns more than 60 percent (approximately 150 acres) of the drainage are upstream of the intake. Nearly the entire watershed is undeveloped, with some timber land and scattered residences.

2.3.1.c Silver Creek

Silver Creek has a total watershed area of 102 acres upstream of its confluence with Boulder Creek. The District previously diverted from an intake at elevation 1,250 feet above mean sea level with a drainage area of 32 acres. The mapped length of Silver Creek upstream of the water intake is approximately 500 feet. When the District diverted water from Silver Creek, it was combined with flows from Peavine Creek and conveyed to the District water treatment plant through about 1 mile of pipeline. The District owns almost the entire Silver Creek watershed, and it is entirely undeveloped, consisting primarily of forest land.

2.3.1.d Clear Creek

Clear Creek has a total watershed area of approximately 1, 050 acres, and joins the San Lorenzo River near Brookdale. The District has three separate water intakes on Clear Creek; one on the mainstem, and two on its tributaries. Water intakes range in elevation from 1,330 to 1,358 feet above sea level. Clear Creek diversions were moved upstream in 1995 to allow gravity conveyance to the District's new treatment plant. The mapped length of Clear Creek upstream of the main-stem diversion is approximately 3,800 feet. Baseflows may be augmented by groundwater recharge within a roughly 300 acre area immediately west of the watershed divide along the crest of Ben Lomond Mountain (Johnson, 2005).

Flows diverted from Clear Creek are conveyed to the District water treatment plant through about 4.5 miles of pipeline. The District owns approximately 264 acres of the Clear Creek drainage upstream of the diversion intakes. Approximately three fourths of the watershed is undeveloped, consisting of timber land, State Park land, and District land. The crest of the watershed includes residential areas with up to 40 septic tank systems.

2.3.1.e Sweetwater Creek

Sweetwater Creek is tributary to Clear Creek, accounting for approximately 30 percent (335 acres) of the total Clear Creek watershed upstream of its confluence with the San Lorenzo River near the community of Brookdale. The District water intake is at elevation 1,330 feet above mean sea level. The mapped length of Sweetwater Creek upstream of the intake is approximately 1,300 feet. The Sweetwater Creek diversion was moved upstream in 1995 to allow gravity conveyance to the District's new treatment plant.

Flows diverted from Sweetwater Creek are conveyed to the District water treatment plant through about 4.5 miles of pipeline. Baseflows may be augmented by groundwater recharged within a roughly 75 acre area immediately west of the watershed divide along the crest of Ben Lomond Mountain (Johnson, 2005). The District owns approximately 27 acres of the drainage area upstream of the intake. Approximately half of the watershed is District and State Park land. The other half contains residential areas that include about 70 septic tank systems.

2.3.1.f Fall Creek

The District owns approximately 252 acres of property in the Fall Creek watershed, also tributary to the San Lorenzo River. The northern boundary of the property is adjacent to Fall Creek State Park, and the southern boundary is adjacent to rural residential land. District water intakes are on Fall Creek, Bennett Springs, and Bull Springs. Fall Creek is steelhead habitat. The property is steep, rugged and forested. It contains several old quarries, historical limekilns, and a network of old logging roads. For more information, refer to Appendix A: Fisheries.

The District has not yet conducted a Drinking Water Source Assessment for Fall Creek to document potential impacts to the District's drinking water sources in the Fall Creek watershed. The Fall Creek property and water rights were acquired from California-American Water in 2008.

2.3.1.g Zayante Creek

The District owns approximately 183 acres of property on both sides of Zayante Creek, which does not serve as a water source for the District. The land is forested, and the creek is good steelhead habitat. The southern property boundary is approximately 3.8 miles north of the intersection of Quail Hollow Road and E. Zayante Road, at the bridge where Zayante Creek flows under E. Zayante Road.

2.3.2 District water supply from surface diversions

The District's newly acquired Felton surface water sources are in the Fall Creek watershed. The California Department of Fish and Game (CDFG) stipulated minimum bypass flows on Fall Creek for the benefit of aquatic habitat. Required minimum bypass flows vary from 0.05 – 1.5 cubic feet per second, depending on the cumulative monthly runoff of the San Lorenzo River, as measured at the Big Trees gage.

To supply its northern service area, the District obtains approximately half its total water supply of 1,600 to 2,100 acre-feet per year (af/yr) from seven surface stream intakes, with a combined contributing watershed area of approximately 1,400 acres on Ben Lomond Mountain.

The District's water rights for its surface water sources on Ben Lomond Mountain do not specify minimum bypass flows. However, CDFG has stipulated that the Clear Creek diversions should not capture the entire flow. The District leaves a minimum bypass flow of 30 gallons per minute (0.07 cubic feet per second) at Clear Creek for the benefit of aquatic habitat.

For more information about the impacts of stream diversions on aquatic habitat, refer to "Chapter 4: Biotic Resources," paragraph 4.6.4.a.

It is within keeping of the District's mission statement to know approximate annual and monthly streamflows, in order to estimate how much water it can divert, and how much to leave in the streams to support aquatic ecosystems. Because of difficult site conditions, there are no streamflow gages on the streams that supply surface water to the District (and none on the San Lorenzo River upstream of the Big Trees gage at Felton). The total average annual discharge of the District's water supply streams has, therefore, been estimated by hydrologists (Geomatrix, 1999). These estimates were based on calculations using available precipitation data in the watershed, and the known annual discharge of streams that are gaged (Geomatrix, 1999).

Thus, Johnson (2008) estimated the combined average annual streamflow of the District's northern system water supply creeks at 4,100 af/yr .Table 2.2 shows the approximate average annual streamflow compared to the average water diverted by the District from these streams.

Table 2.2. Estimated average annual streamflow of District surface streams (northern system), amount and percentage diverted.

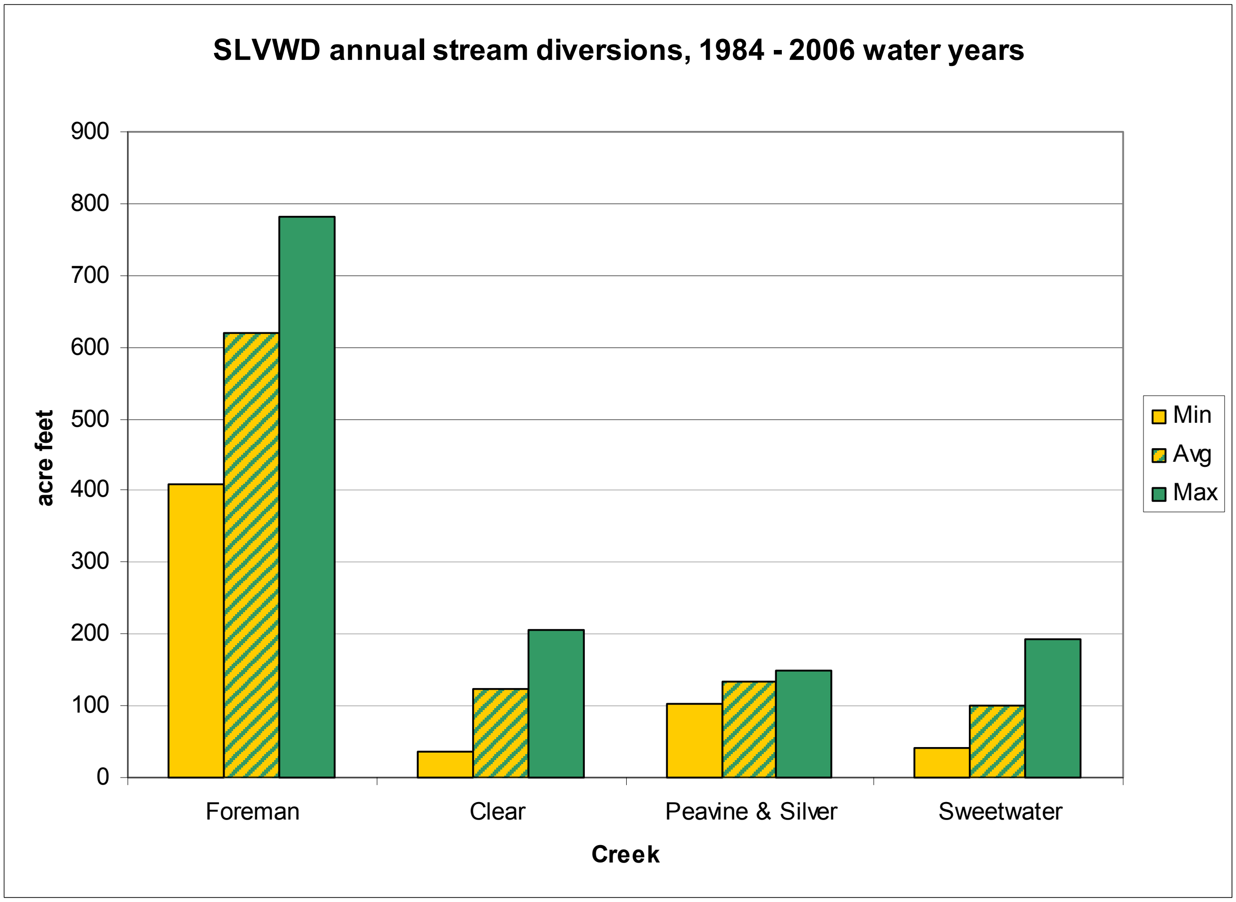
District supply creek (at diversion point)	**Total streamflow** (af/yr)	**Water diverted** (af/yr)	**% of total streamflow**
Foreman	1,400	621	44
Clear	1,300	124	10
Peavine & Silver	800	135	17
Sweetwater	600	101	17
Totals	4,100	981	24

Source: Johnson, 2008 (Table 4-3 and paragraph 4.1.3)

The total estimated annual streamflow (4,100 af/yr) of these District supply streams represents approximately 8 percent of the estimated average flow of the San Lorenzo River at Clear Creek (50,000 af/yr), and 4 percent of the estimated average flow of the San Lorenzo River at Big Trees (96,700 af/yr) (Johnson, 2008).

Figure 2.5 shows the annual minimum, maximum and average flows diverted by the District, from 1984-2006.

Figure 2.5. Annual minimum, maximum and average flows diverted from northern system creeks, water years 1984 – 2006.



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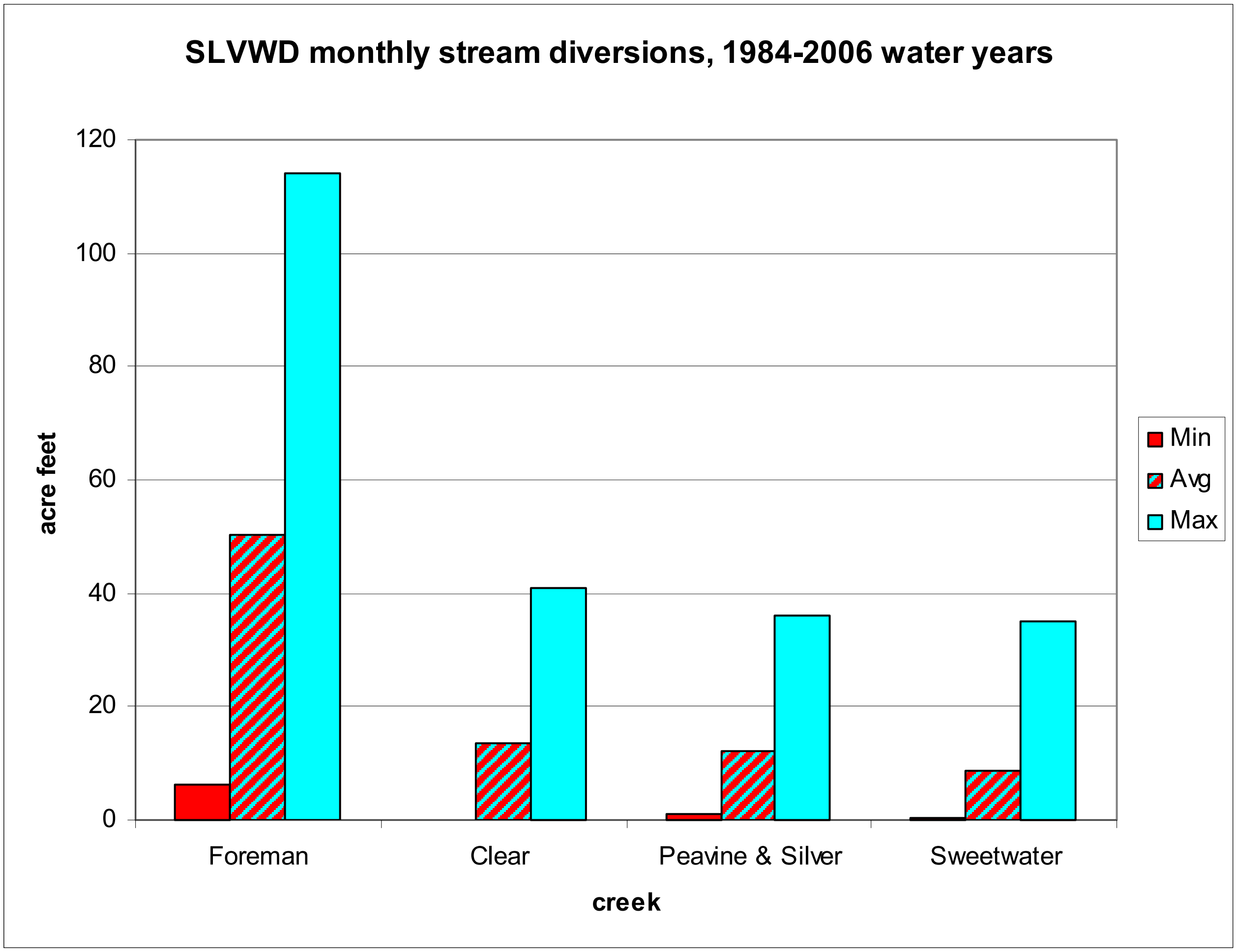
Source: Johnson, 2007 (data from Table 4-3)

Figure 2.6 shows the *monthly* minimum, maximum and average flows diverted from the same creeks. Total monthly stream diversions averaged about 74 acre feet, but have declined to as low as 13 acre feet in September 1988. The total maximum monthly rate of diversion during the period of record was 138 acre feet.

Figure 2.6. Monthly minimum, maximum and average flows diverted from the District's northern system creeks



Source: Johnson, 2007 (Table 4-13)

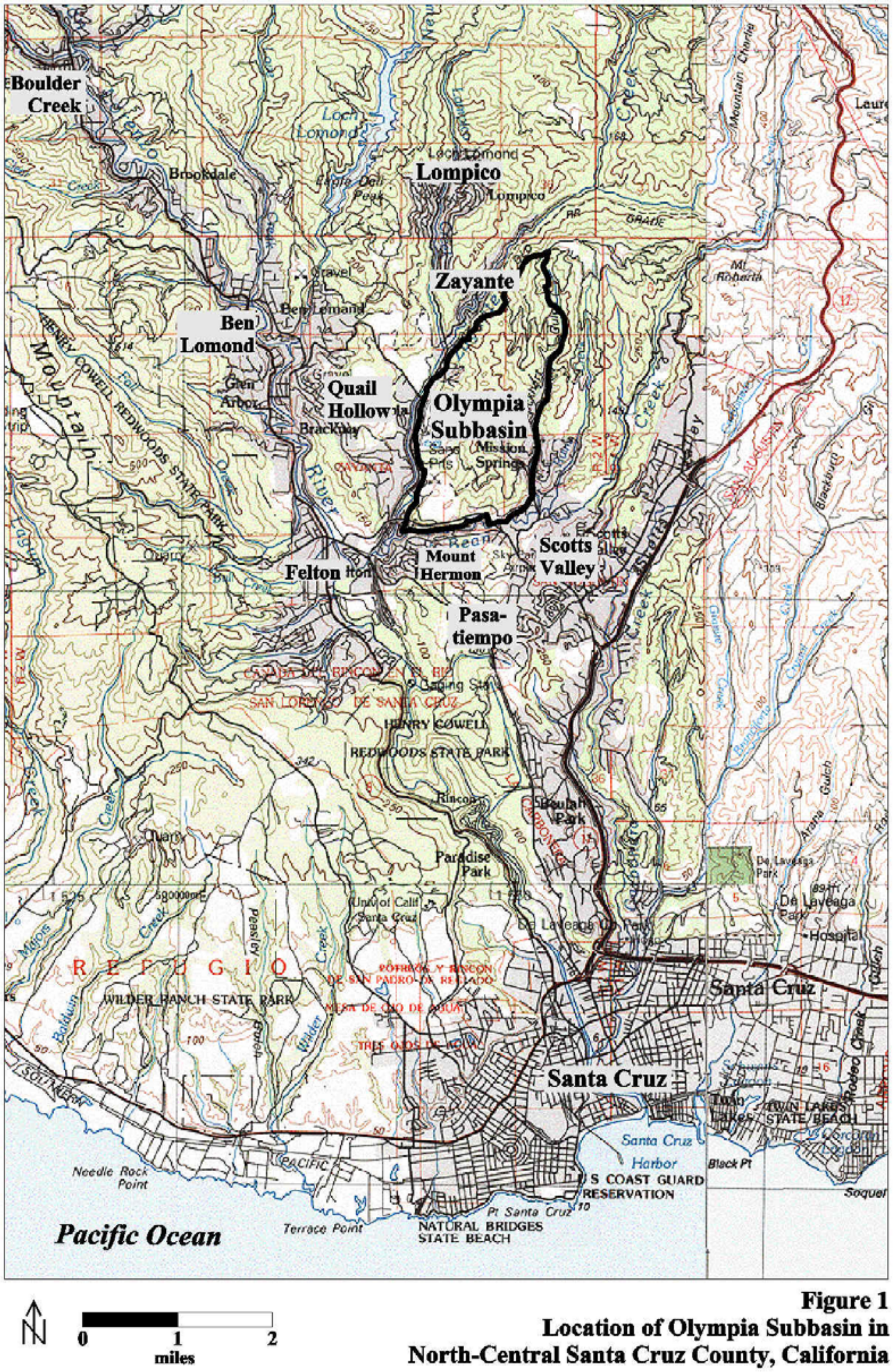
2.3.3 District wells and groundwater recharge lands

The District's wells are located in four different locations, and tap two different aquifers. The District owns approximately 167 acres of land that serve as protective buffers for its wells. For information about groundwater storage, recharge, and water quality issues that affect the District's groundwater sources, refer to "Chapter 3, Hydrology, Geomorphology, and Water Quality."

2.3.3.a The Olympia wellfield

The District's two Olympia wells draw from a three square mile area northeast of Felton and northwest of Scotts Valley, bounded by Zayante Creek to the west, Lockhart Gulch to the east, and Bean Creek to the south, as shown in Figure 2.7. The Santa Margarita Sandstone aquifer is the source of groundwater for the wells. The overall capture zone for the Olympia wells is approximately 1,200 acres, of which the District owns 163 acres. Groundwater recharge to the District's Olympia wells is derived primarily from percolating rainfall. Land use in the recharge area includes a closed sand quarry, undeveloped open space including timberland, and rural residential development (Johnson, 2002). For a more detailed discussion of potential impacts to groundwater recharge and water quality, refer to Chapter 3.

Figure 2.7. Location of the Olympia ground water basin



Source: Johnson, 2002.

2.3.3.b Quail Hollow wells

The Quail Hollow area is approximately three square miles, lying between Zayante and Newell creeks and the San Lorenzo River. The Santa Margarita Sandstone aquifer underlies the hillslope area of Quail Hollow. The District operates two wells in the Quail Hollow area. The primary recharge area for these wells is 200 acres or more, depending on water table conditions, of which the District owns approximately 4 acres. However, the entire square mile Santa Margarita exposure is important to the balance that contributes to the District wells.

Figure 2.8 shows the location of the Quail Hollow Basin.

Figure 2.8. Location of the Quail Hollow ground water basin

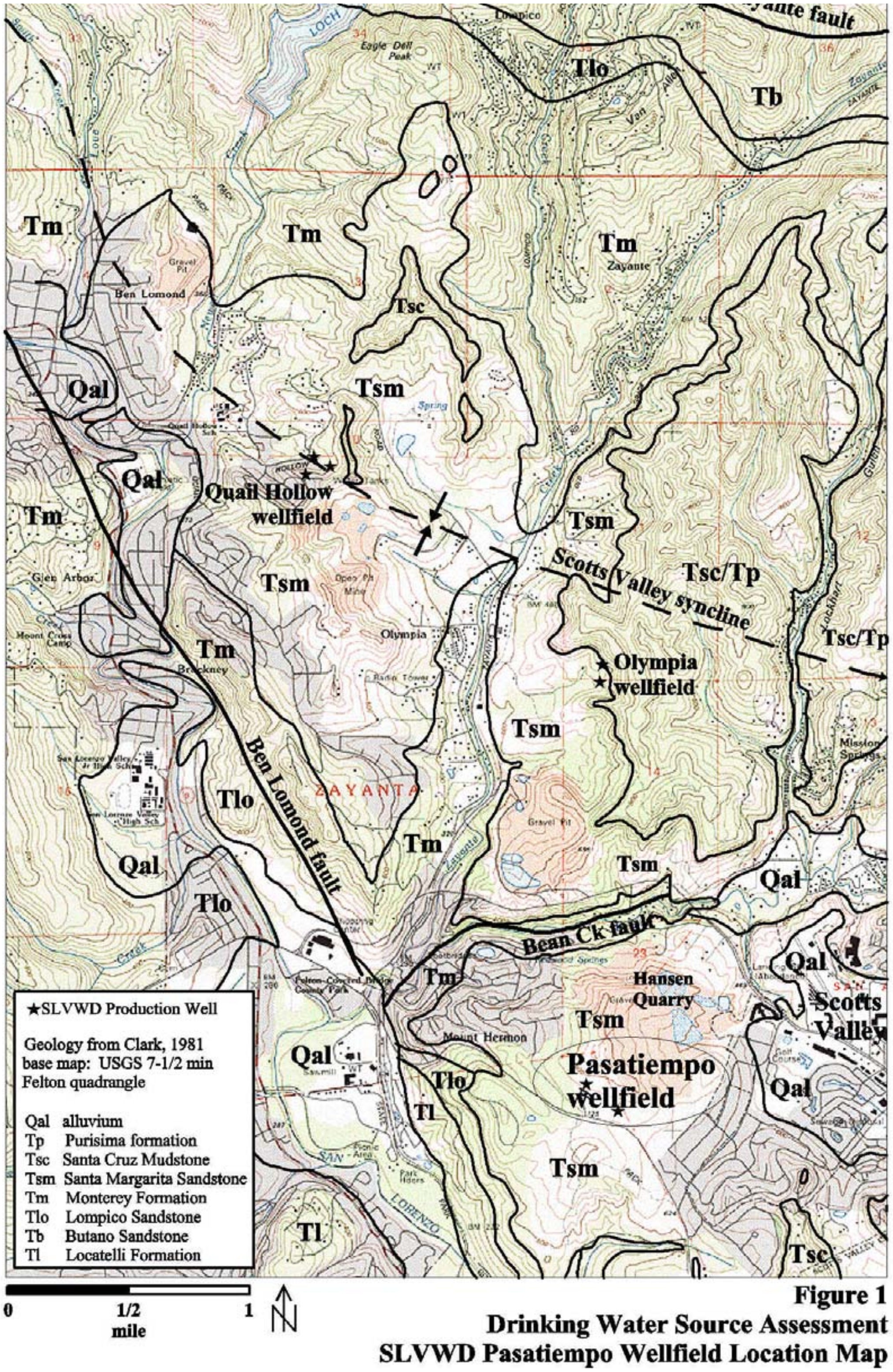
Source: Johnson, 2002.

2.3.3.c Pasatiempo wells

The District's two Pasatiempo wells are located near southwestern Scotts Valley, east of the San Lorenzo River, south of Bean Creek, west of Carbonera Creek, and north of Eagle Creek. The wells draw from the Lompico Sandstone aquifer, and have a recharge area of slightly more than 500 acres, of which the District owns 1.2 acres (well and tank sites).

Figure 2.9 shows the location of the Pasatiempo wellfield.

Figure 2.9. Location of the Pasatiempo wellfield



Source: Johnson, 2002.

2.3.3.c Mañana Woods well

The sole water source for the District's Mañana Woods service area in Scotts Valley is a well located on Kings Village Drive. The Mañana Woods well is located approximately ½ mile from the unincorporated Mañana Woods area south of Mt. Hermon Road in Scotts Valley. The water is treated at the site and pumped via mains to storage tanks within the service area. The District annexed the Mañana Woods water system in 2006.

ACKNOWLEDGMENTS: CHAPTER 2

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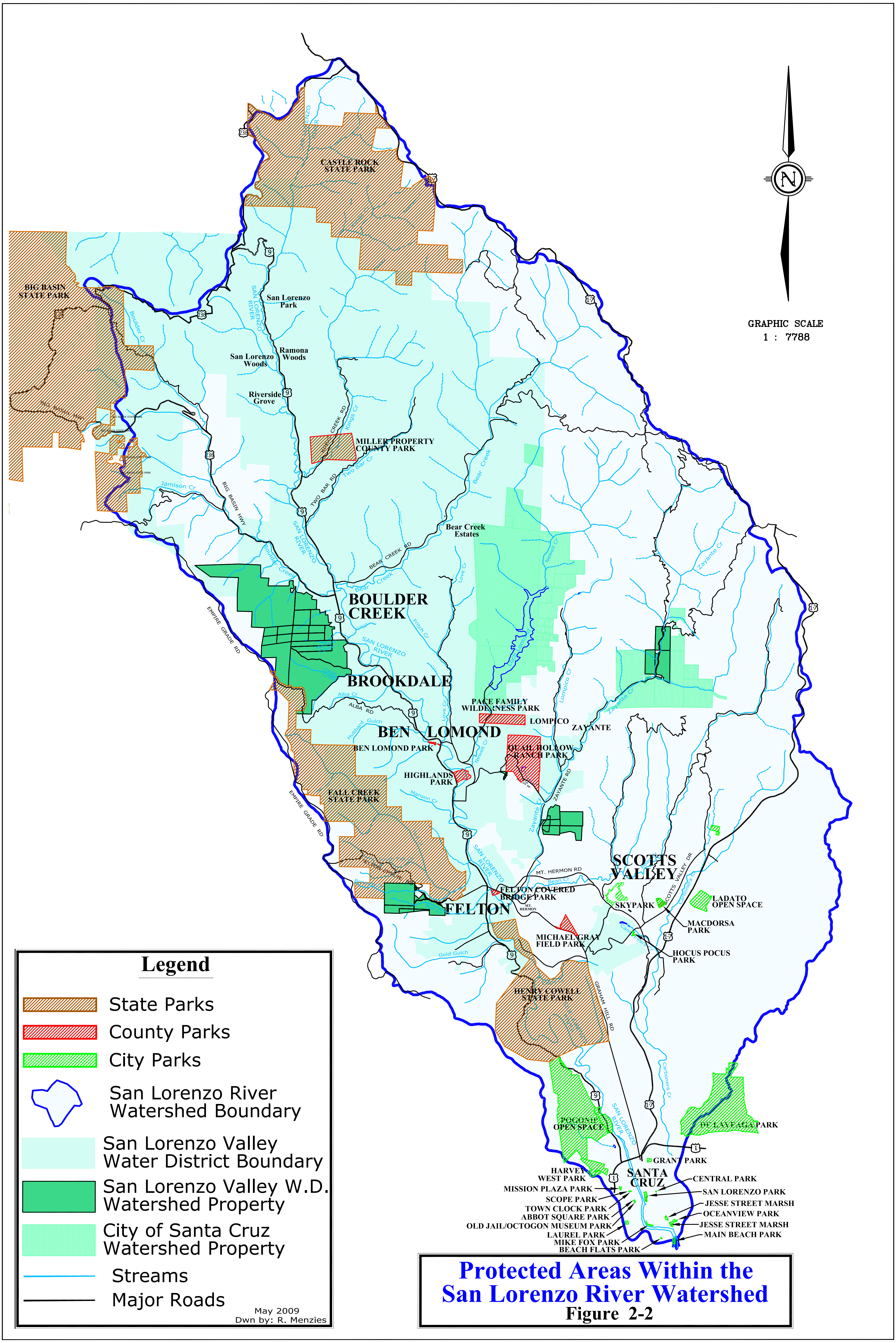


Protected Areas Within the San Lorenzo River Watershed

Figure 2-2

CHAPTER 3: HYDROLOGY, GEOMORPHOLOGY & WATER QUALITY

3.0 Introduction

This chapter describes the natural processes and human impacts that have influenced the landscape from which the District's water supply flows. The chapter begins with an overview of landscape evolution, describing the natural processes and human activities that have contributed to shaping the landscape. The chapter then provides an overview of the geology and soil types. Finally, the chapter discusses human impacts and land use activities in terms of their impacts to water quality.

Hydrology is the study of the distribution of water on and near the earth's surface. Because the amount of water is finite, it constantly moves through the hydrologic cycle in processes known as precipitation, infiltration, percolation and groundwater storage, evaporation and transpiration, and surface water runoff.

Geomorphology is the study of landforms, their origin and evolution, and the processes that shape them. Landforms can be characterized by their elevation, slope, orientation, stratification, rock exposure, and soil type. The science of geomorphology seeks to explain why landscapes appear the way they do, and it seeks to use this information to predict future changes. Landscapes include landforms, climatic factors, flora and fauna, and the built environment.

Scientists predict that climate change will increasingly impact the hydrologic cycle, but the degree and severity of the impacts of climate change on local watersheds and water supplies is not known. Scientific research applicable to the central California coast indicates that climate change will bring increasingly higher temperatures, more extreme droughts and more intense rainfall. All of these factors are expected to impact the local region's water resources. Chapter 7: Local Climate Change Assessment presents a more detailed discussion of the impacts of climate change, as well as potential adaptation and mitigation actions.

3.1 Overview of landscape evolution

This section begins with an overview of the geologic processes that formed and continue to shape the Santa Cruz Mountains as a region. It then describes the three geologic areas of the San Lorenzo River watershed, and their soil types. Finally, it summarizes the role of human influences on the landscape, resulting from land use changes that began about 200 years ago.

3.1.1 Geologic formation of the Santa Cruz Mountains

According to the theory of plate tectonics, the earth's crust is formed by a number of rigid plates, which move under (a process known as subduction) and against each other, causing major dynamic events, such as uplift of mountain ranges, and earthquakes (Harden, 1998). About 145 million years ago, the Farallon Plate began to collide with the North American Plate, resulting in the subduction of the Farallon plate. During this subduction, parts of the Farallon plate were scraped off onto the North American Plate in a process called accretion (Sloan, 2006). This accretion took place over a period of about 100 million years, producing the Mesozoic rocks in today's Bay Area (Sloan, 2006).

About 28 million years ago, the subduction of the Farallon Plate was complete, bringing the Pacific Plate into direct contact with the North American Plate. Movement between these two plates no longer involved subduction. Instead, the Pacific Plate slipped northward against the North American Plate, in a roughly parallel fashion, along the San Andreas Fault, which extends from Cape Mendocino to the Gulf of California. About 3-4 million years ago, the Pacific Plate shifted slightly to move obliquely to the North American Plate (Harden, 1998). This shift caused the two plates to converge, and this tectonic compression of the earth's crust caused the uplift of the Coast Ranges of California, including the Santa Cruz Mountains. This compression continues today, and the Coast Ranges continue to be uplifted. For example, the 1989 Loma Prieta earthquake caused the Santa Cruz Mountains west of the San Andreas Fault to rise approximately 1.2 meters (Harden, 1998).

This uplift exposed older geologic units--predominately marine sedimentary rocks--to weathering, to surface erosion, and to erosion from mass wasting and landslides. Recent geologic and climatic conditions, associated with the end of the last ice age, formed stream valleys and drainage networks, through surface erosion and mass wasting. This weathering produced soil, a mix of inorganic minerals and organic matter. These initial soils formed the basis of life for surface vegetation, microbes, and bacteria. Alluvium or "geologic erosion" from these natural processes line most stream valleys in the San Lorenzo River watershed.

3.1.2 Geologic formation of the San Lorenzo River watershed

Within the San Lorenzo River watershed, movement along local fault zones formed three distinctive geologic areas (Hecht & Kittleson, 1998; Swanson Hydrology & Geomorphology, 2001), each with different soil types. The Ben Lomond Mountain geologic unit, on the west side of the watershed, is the source of all of the District's surface water. The District's ground water is supplied from a different geologic area, with different soil types. These geologic areas are depicted in Figure 3-10, and described in detail in Section 3.3, Geology and Hillslope Geomorphology.

3.1.3 Human impacts from land use changes

Landscape evolution of the region and the San Lorenzo River watershed also reflects very recent and profound changes in human land use patterns.

Changes in land-use practices that occurred between 1800 and 1910 caused significant impacts to vegetation, as well as geomorphic and hydrologic processes. Plants that existed prior to introduction of European land uses in the early 1800s were adapted to existing climatic and prehistoric land-use conditions. These conditions have been described by early expeditions of white settlers and explorers, and included the practice of setting fires by Native Americans.

Most of the forested land within the San Lorenzo River watershed was clearcut. Streams were diverted, and roads were built. Today, these are known as "legacy" conditions. Effects of legacy land use were immediate and profound, and some effects are ongoing. Legacy roads and railroad grades caused chronic erosion. As hillslope erosion increased, more sediment was delivered to stream valleys, deepening alluvial deposits and filling stream channels with sediment. Streams would eventually flush out the excess sediment, but higher, unconsolidated stream banks, more prone to erosion, would result. As the human population grew within the watershed, roads and development also increased. The continued use of logging roads as residential access roads created chronic sources of erosion and sedimentation. The pervasive road network, especially unpaved and poorly maintained roads, continues today as the most persistent sources of sedimentation to streams (Santa Cruz County Planning Department, 1998, CCRWQCB staff report for TMDL, 2002). As previously mentioned, county and state agencies have initiated grant-based programs to address some of the problems of these poorly constructed and maintained roads.

3.2 Hydrologic processes

This section summarizes available information for the larger San Lorenzo River watershed, as well as information specific to the District's water supply sub-watersheds and aquifers. Hydrological processes include precipitation, evapotranspiration, streamflow and diversions, groundwater storage, and recharge.

3.2.1 Precipitation in the San Lorenzo River watershed

Three precipitation measurement stations in the watershed have relatively long records: the Santa Cruz and Ben Lomond 4 NOAA stations and the station near the crest of Ben Lomond Mountain now maintained by the nearby Lockheed facility. The available monthly records of these three stations extend back to 1931, 1973, and 1959, respectively. Annual rainfall at Santa Cruz, Ben Lomond, and Lockheed averages approximately 30, 50, and 55 inches per year (in/yr), respectively. Monthly rainfall records maintained by the District since 1981 at its office in Boulder Creek correlate reasonably well with the Ben Lomond 4 annual record. Average rainfall at both stations is about 50 in/yr. (Johnson, 2008. In progress).

Mean annual rainfall exceeds 60 inches along the crest of Ben Lomond Mountain. Figure 3.1 shows mean annual precipitation on Ben Lomond Mountain and the San Lorenzo River watershed to the east of the ridge. The highest rain per day recorded since 1972 for Ben Lomond was 11.46 inches on January 4, 1982 (Ben Lomond Station 040673, 2003). In 1982, the calendar year of highest recorded precipitation for the watershed, the District recorded 111.48 inches, as shown in Table 3-1. The driest recorded year for the watershed was during the drought of the late 1970s, with 22.14 inches of rainfall recorded by the District during the water year 1976-77 year, as shown in Table 3-1.

Approximately 90 percent of annual rainfall occurs between November and April. During the rainy season, six to ten consecutive days of rainfall is not unusual for the San Lorenzo River watershed (Swanson Hydrology & Geomorphology, 2001).

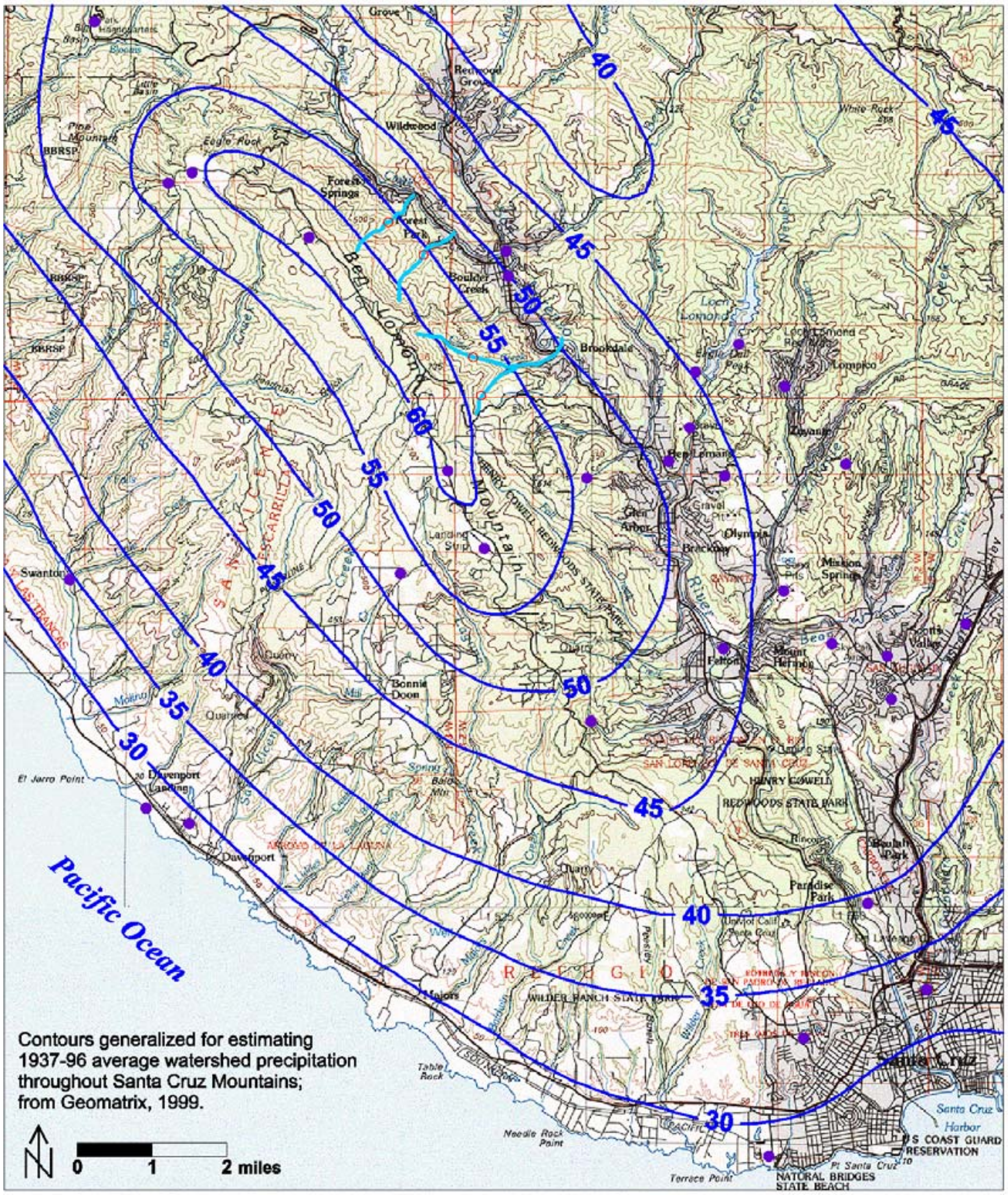
A prolonged 19-year drought occurred in water years 1917-1935, with 80 percent or less of average rainfall. Significant droughts also occurred in water years 1975-77 and 1987-94, with approximately 60 and 75 percent of average rainfall, respectively. Water year 2006-2007 was the driest since 1994.

Coastal fog delivers an unknown amount of moisture, mostly during the summer months. Singer (In Swanson Hydrology & Geomorphology, 2001) cited research (Jacobs, et al. 1985) regarding fog drip data collected on similar ridgetop redwood forests that were different distances from the ocean. In the Muir Woods area, during a six-week period in September – October, Jacobs et al. (1985) recorded 4.38" of fog drip precipitation on the first inland ridge (less than one mile from the ocean) and only 0.24" of fog drip precipitation on the third inland ridge (slightly less than three miles from the ocean). Singer suggested that:

> Valleys that trend north-to-south with bordering ridgelines more than 1500 – 1700 feet high can block the direct incursion of fog. Such is the case in the San Lorenzo Valley, where stratus must move up the valley from the south because of Ben Lomond Mountain (2600' elevation) to the west. Consequently Boulder Creek has fewer overcast or fog days than Felton. If the roof of the stratus layer is high enough, stratus fog can enter the upper San Lorenzo Valley by spilling over Waterman Gap (1267' elevation) from the Pescadero Drainage, as we have observed on numerous occasions (Swanson Hydrology & Geomorphology, 2001).

Because no known local studies have been conducted on fog drip, it is unknown how much fog drip contributes to the local water supply. Based on studies of other areas, Swanson Hydrology & Geomorphology (2001) estimated that fog drip provides a small but significant amount of precipitation, probably 5 or less inches annually, to the City of Santa Cruz watershed lands, which are similar in vegetation, elevation and orientation to SLVWD's watershed lands.

Figure 3.1. Mean annual precipitation (inches/year) on Ben Lomond Mountain



● Precipitation station
o District stream diversion
Source: Johnson, 2002

Table 3-1. Monthly rainfall record for Ben Lomond 4 NOAA Station, Water Years 1973-2007 (Inches)

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Percent of Avg	
1973				14.55	19.08	5.57	0.13	0.00	0.00	0.00	0.00	0.33			
1974	4.62	14.73	9.11	7.55	2.40	13.00	4.15	0.00	0.35	1.66	0.00	0.00	57.57	116%	100%
1975	2.78	2.30	7.26	1.70	10.80	12.25	3.68	0.04	0.19	0.13	0.79	0.03	41.95	85%	
1976	6.76	0.67	0.81	0.31	4.56	2.12	2.60	0.03	0.20	0.03	1.73	1.78	21.60	44%	42%
1977	0.45	2.97	3.65	2.87	1.99	3.83	0.37	1.29	0.03	0.05	0.00	2.47	19.97	40%	
1978	0.59	5.76	10.61	24.77	10.27	9.89	6.95	0.02	0.04	0.02	0.00	1.79	70.71	143%	119%
1979	0.00	5.50	1.82	12.88	13.26	6.13	1.60	1.14	0.00	0.30	0.04	0.02	42.69	86%	
1980	5.65	3.47	11.02	13.55	19.20	2.90	3.98	0.71	0.27	0.66	0.01	0.02	61.44	124%	
1981	0.08	0.25	6.31	12.14	3.89	9.85	0.15	0.13	0.00	0.00	0.00	0.22	33.02	67%	
1982	2.83	13.33	10.42	23.02	6.91	13.98	8.34	0.04	0.26	0.01	0.08	1.27	80.49	162%	
1983	4.07	13.14	9.20	15.16	20.35	22.61	8.62	1.05	0.04	0.00	0.34	1.07	95.65	193%	
1984	1.29	16.50	13.34	0.77	3.08	3.10	1.47	0.16	0.34	0.03	0.00	0.17	40.25	81%	
1985	3.60	14.81	3.65	1.46	5.56	9.61	0.68	0.16	0.27	0.17	0.03	0.68	40.68	82%	
1986	1.31	7.73	6.13	10.64	24.20	14.43	0.76	0.51	0.00	0.05	0.06	1.38	67.20	136%	
1987	0.14	0.11	3.12	5.85	9.86	7.02	0.63	0.00	0.11	0.02	0.00	0.00	26.86	54%	71%
1988	1.58	4.33	12.07	5.64	0.88	0.06	4.30	1.31	0.11	0.02	0.00	0.01	30.31	61%	
1989	0.39	6.95	9.44	1.16	2.23	11.34	1.20	0.25	0.07	0.00	0.11	1.15	34.29	69%	
1990	3.75	2.03	0.06	4.61	4.89	2.52	0.42	5.76	0.01	0.00	0.08	0.17	24.30	49%	
1991	0.67	0.47	2.52	0.70	5.32	20.52	0.99	0.17	0.46	0.02	0.11	0.05	32.00	65%	
1992	3.53	2.24	6.55	3.92	16.95	6.16	0.68	0.06	0.93	0.02	0.05	0.02	41.11	83%	
1993	4.08	0.51	13.36	20.98	12.24	3.06	1.73	1.03	0.66	0.00	0.00	0.05	57.70	116%	
1994	0.75	3.78	6.65	3.86	11.36	0.97	3.23	2.42	0.04	0.00	0.00	0.03	33.09	67%	
1995	1.32	10.61	5.54	26.51	1.17	15.88	5.14	1.78	1.11	0.01	0.00	0.00	69.07	139%	126%
1996	0.00	0.39	12.24	17.48	16.39	5.61	3.64	5.35	0.04	0.00	0.00	0.00	61.14	123%	
1997	2.64	9.23	24.51	18.41	0.29	1.66	0.82	0.16	0.25	0.00	0.73	0.00	58.70	118%	
1998	0.81	13.08	5.55	19.34	27.98	5.89	4.05	6.00	0.07	0.00	0.00	0.03	82.80	167%	
1999	1.14	8.59	2.45	11.04	11.79	6.84	3.82	0.04	0.29	0.00	0.04	0.27	46.31	93%	
2000	0.44	6.06	0.95	19.14	20.77	2.93	3.86	1.22	0.20	0.00	0.13	0.54	56.24	114%	
2001	6.34	1.68	1.26	10.22	11.38	3.85	*2.36*	0.00	0.12	0.00	0.01	0.07	37.29	75%	90%
2002	1.19	10.87	20.21	4.93	3.23	5.41	0.45	*1.00*	0.00	0.00	0.03	0.00	47.32	96%	
2003	0.00	7.43	24.77	2.52	3.15	2.44	7.52	1.10	0.08	0.00	0.00	0.00	49.01	99%	
2004	*0.00*	4.49	19.39	6.14	11.33	1.65	0.80	0.05	0.00	0.01	0.00	0.20	44.06	89%	
2005	8.70	4.24	15.49	11.83	8.05	10.36	4.35	2.47	1.26	0.00	0.00	0.11	66.86	135%	143%
2006	0.22	4.02	25.95	7.20	5.90	16.84	13.58	0.91	0.00	0.00	0.00	0.00	74.62	151%	
2007	1.19	3.90	7.12	1.31	11.59	0.43							*25.54*	*52%*	
Avg	2.14	6.06	9.19	9.83	9.78	7.45	3.15	1.07	0.23	0.09	0.13	0.41	49.54	99%	99%
Min	0.00	0.11	0.06	0.31	0.29	0.06	0.13	0.00	0.00	0.00	0.00	0.00	19.97	40%	42%
Max	8.70	16.50	25.95	26.51	27.98	22.61	13.58	6.00	1.26	1.66	1.73	2.47	95.65	193%	143%
% of Avg	4.3%	12%	19%	20%	20%	15%	6.4%	2.2%	0.5%	0.2%	0.3%	0.8%	100%		

Italics indicate estimates
Sources: www.ncdc.noaa.gov/coop-precip/california.txt; www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?cabenl+nca
Station elevation 450 ft msl.

3.2.2 Streamflow in the San Lorenzo River watershed

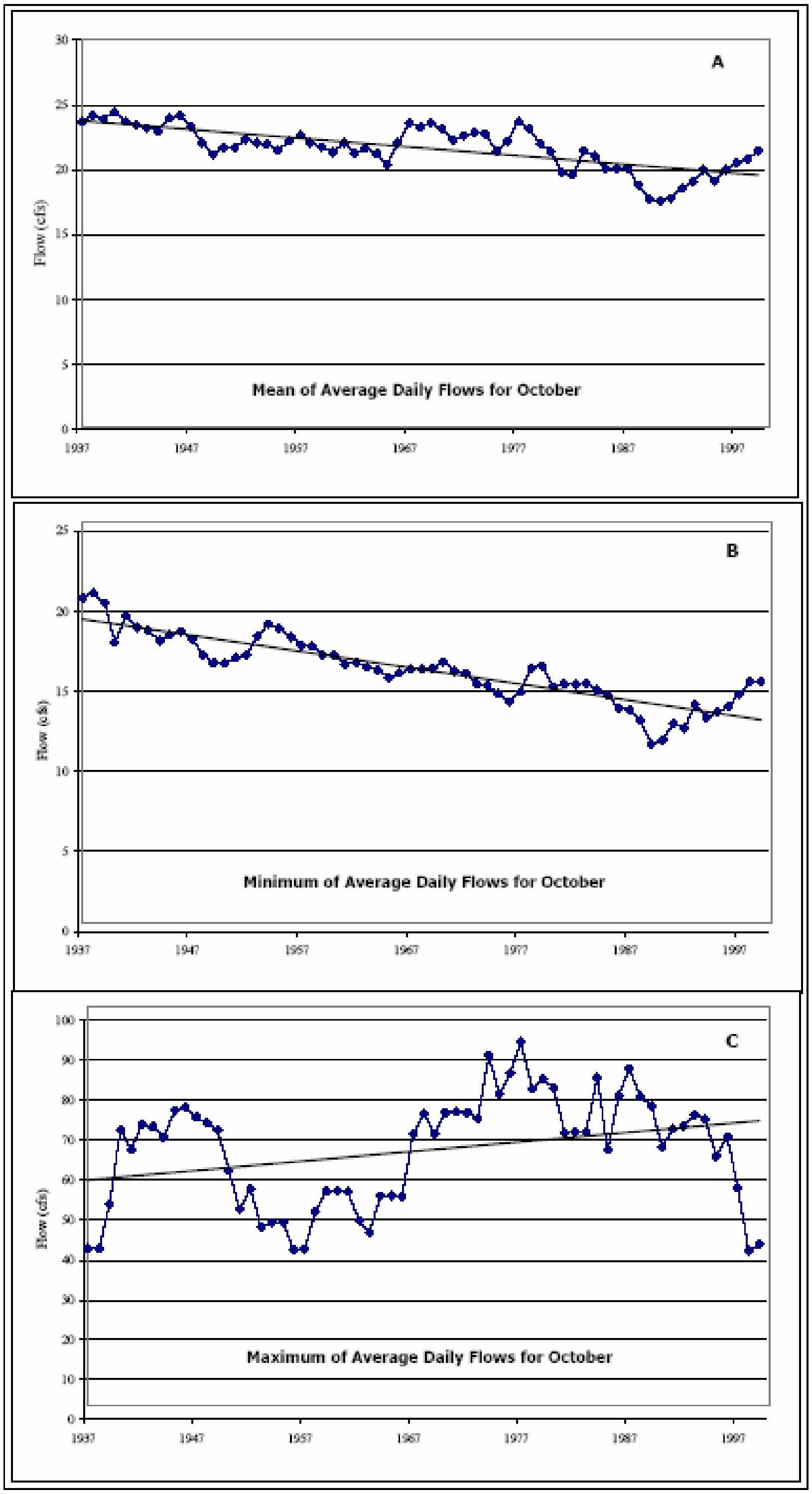
Streamflow is directly related to rainfall. Winter streamflow generally does not markedly increase until soil saturation occurs, after the initial rains of the season, with the highest flows typically occurring from late December through March. Once soils have reached saturation level, streamflow responds quickly to rainfall. Streamflow peaks in great spikes periodically in response to episodic storm events.

As shown in Figure 3.2, Alley ET. al (2004) found that mean streamflows in the San Lorenzo River, measured at the USGS Big Trees station during October, decreased 17.2% between 1937 and 1997, while minimum baseflow decreased 32.1%. (October is typically the month with the lowest streamflows.) They suggested that these decreases were the result of increased surface diversions and well pumping over the same period, in addition to a possible reduction in late season rainfall.

> The impact of surface diversions, reservoir construction, and well pumping becomes clearer after reviewing the December trends [as shown in Figure 3-3]. Mean and maximum streamflow falls 36.2% and 46.2%, respectively. The magnitude of these reductions, particularly for the mean value, is significantly higher than all other months except for April. A viable explanation for the observed flow reductions is that groundwater pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased. Historically, rains in October and November would percolate into groundwater reservoirs, allowing rains in December through March to contribute more directly to runoff. The capture of initial runoff in Loch Lomond before it spills would also contribute partially to a reduced December maximum flow after 1960 (Alley et. al, 2004).

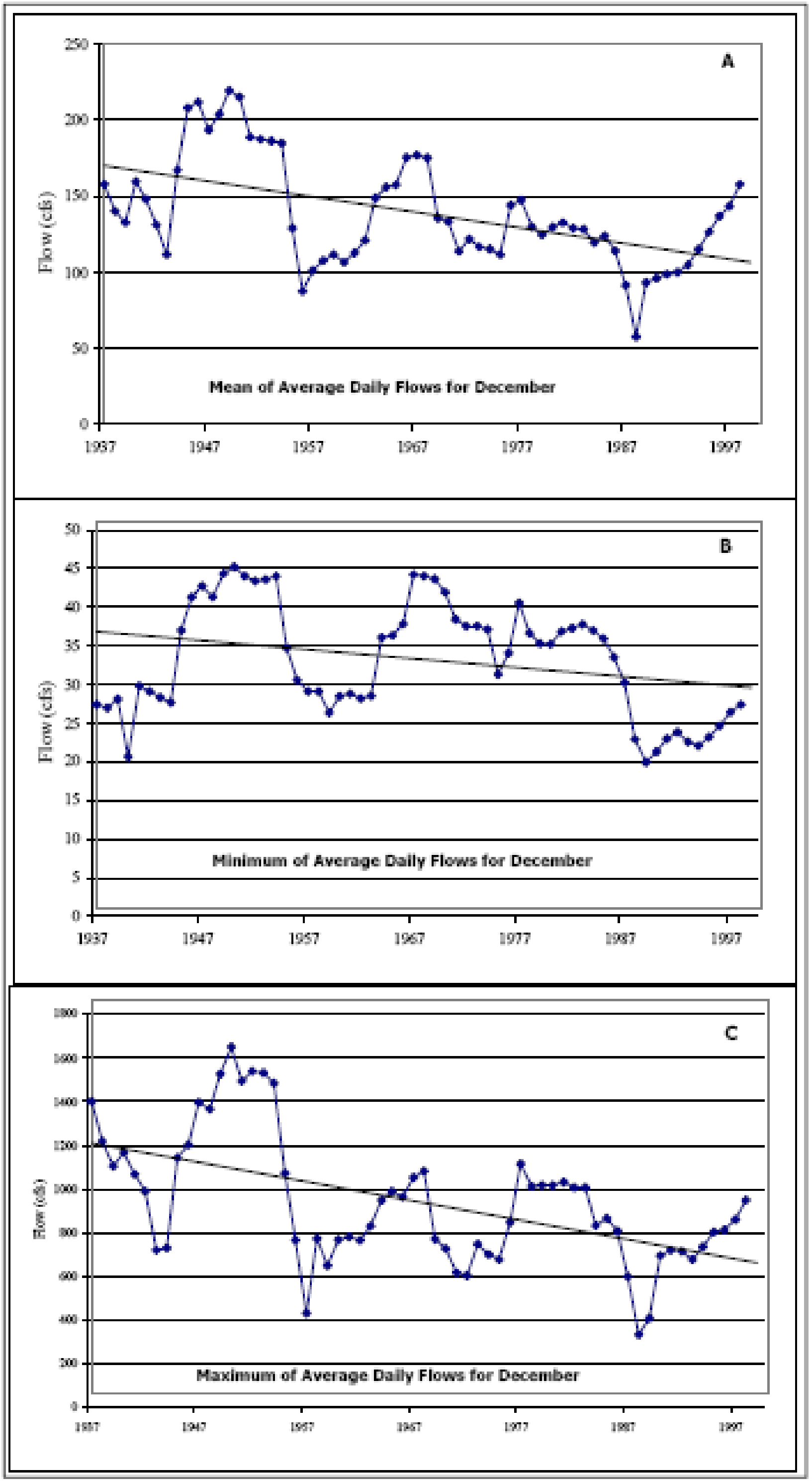
Decreased water flows affect aquatic habitat and every species that relies on such habitat qualities. Management practices to maximize summer flows would considerably benefit the production of yearling sized juvenile salmonids, thereby directly increasing the number of returning adults for the spawning population. For more information about how reduced streamflows affect salmon and steelhead, refer to “Appendix A: Fisheries.”

Figure 3.2. San Lorenzo River average daily flows for the month of October, 1937-1997, measured at Big Trees



Source: Alley et al., 2004.
11-year moving average for October, with trend line for the last 60 years. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

Figure 3.3 San Lorenzo River average daily flows for the month of December, 1937-1997, measured at Big Trees



Source: Alley et al., 2004

11-year moving average for December, with trend line for the last 60 years. The 1955 Water Year was removed from the analysis due to extremely high flows that acted as an outlier. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

3.2.3 Precipitation and streamflow in District water supply streams

Surface water streamflow depends largely on precipitation. The District's monthly diversions from Foreman Creek typically peak in March, in response to peak-seasonal rainfall. Diversions from the other streams typically peak in June as seasonal water demand surpasses the Foreman Creek diversion. Total diversions typically peak in May.

Table 3.2 shows the average precipitation and streamflow for the District's surface water supply creeks on Ben Lomond Mountain.

Table 3.2 Average precipitation and streamflow for District surface water supply creeks

Watershed Upstream of SLVWD Intake	Estimated Average Precipitation (inches/yr)	Estimated Stream Discharge from Watershed Precipitation		Estimated Evapo-transpiration (inches/yr)	Est. Add'l Ground-water Discharge*	Estimated Total Average Discharge		Estimated 1984-1997 Range in Monthly Discharge Min - Max		Estimated Peak Discharge 1/4/82**
		(inches/yr)	(ac-ft/yr)		(ac-ft/yr)	(ac-ft/yr)	(cfs)	(cfs)		
Peavine Ck	60.2	29.2	588	30.9	159	750	1.0	0.1	10	120
Silver Ck	58.3	28.0	74	30.3	21	94	0.1	-	-	20
Foreman Ck	60.0	29.1	1,169	30.9	230	1,400	1.9	-	-	230
Clear Ck	60.3	29.3	1,071	31.0	200	1,270	1.8	0.2	17	210
Sweetwater Ck	60.3	29.3	524	31.0	70	590	0.8	0.1	8	100
Total or Average	60.1	29.2	3,425	30.9	680	4,100	5.7	0.5	55	680

*Recharge from outside watershed.
**Estimated from Boulder Creek gaged 1/4/82 peak based on ratio of watershed areas.
Source: Geomatrix Consultants, March 1999

3.2.4 Groundwater pumping and streamflow in the San Lorenzo River watershed

The San Lorenzo River Salmonid Enhancement Plan, (Alley et al., 2004) addressed groundwater extraction as another significant, yet difficult to track, source of flow reduction.

> Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation (Alley et al., 2004).

According to Santa Cruz County, since 1986, the decline of groundwater levels has significantly reduced water levels in the Santa Margarita sandstone aquifer in the Pasatiempo Unit and Camp Evers areas, reducing baseflow in Bean Creek, Carbonera Creek, and the San Lorenzo River. The decline has also reduced available water supplies for the District, and other water agencies including Scotts Valley Water District, the City of Santa Cruz, and Mt. Hermon Association, Inc. (Todd Engineers, 2004; Watkins-Johnson, 1993).

It seems reasonable to assume that overdraft of the Scotts Valley groundwater basins has reduced summer baseflows to creeks draining the area underlain by the Santa Margarita, but a District draft hydrological study of Bean Creek has not confirmed this assumption (Johnson, 2002). As a result, the District's consulting hydrologist theorized that the perching layer beneath the channel causes flows from upper Bean Creek, and groundwater discharge from the north, to mostly ride along the top of this layer, at least until bypassing the pumping depression. This theory could also account for flow declines in late fall and early winter, which are shown in Fig. 3.2. Increasingly depressed groundwater levels in the Santa Margarita may increasingly "suck up" early season stormflows in creeks flowing above it, but this action occurs during a season when the flows average greater than baseflow. Since more data is available for Bean Creek than for Newell, Zayante, Carbonera, Creeks, it offers the best opportunity for quantitative analysis of potential flow impacts.

3.2.5 District groundwater storage and recharge

The District's wells draw from the Lompico Sandstone aquifer and the Santa Margarita Sandstone aquifer. The Santa Margarita Sandstone aquifer supplies the District's Olympia and Quail Hollow well fields.

3.2.5.a The northern service area

Groundwater recharge to the Olympia wells is derived primarily from percolating rainfall. Groundwater occurs under unconfined conditions in the Olympia area, even where the aquifer is overlain by mudstone. **(**Unconfined conditions means that the groundwater aquifer does not have a confining layer between it and the surface. Unconfined aquifers usually receive recharge water directly from the surface, from precipitation or from a body of surface water connected with it.) Because of the synclinal fold, the aquifer becomes unsaturated to the north and south and is not in direct hydraulic contact with either Bean Creek or upper Zayante Creek. The aquifer base also rises to the west where the sandstone has been mostly eroded away along Zayante Creek. As such, the aquifer is generally not in direct contact with the portion of Zayante Creek nearest to the wellfield, with the exception of an approximately 700-foot long stretch where a thin band of sandstone crosses the creek between the Olympia and Quail Hollow areas.

The recharge area for the Olympia wellfield is rural and undeveloped, and much of the aquifer lies beneath less permeable mudstone. An old quarry immediately west of the wells serves as a stormwater retention basin that recharges the aquifer, and receives stormwater from a relatively undeveloped area, as shown in Figure 3.4.Where the aquifer is exposed to the surface, it has a high percolation capacity.

Figure 3.4. The old Olympia quarry immediately west of the District's Olympia wells

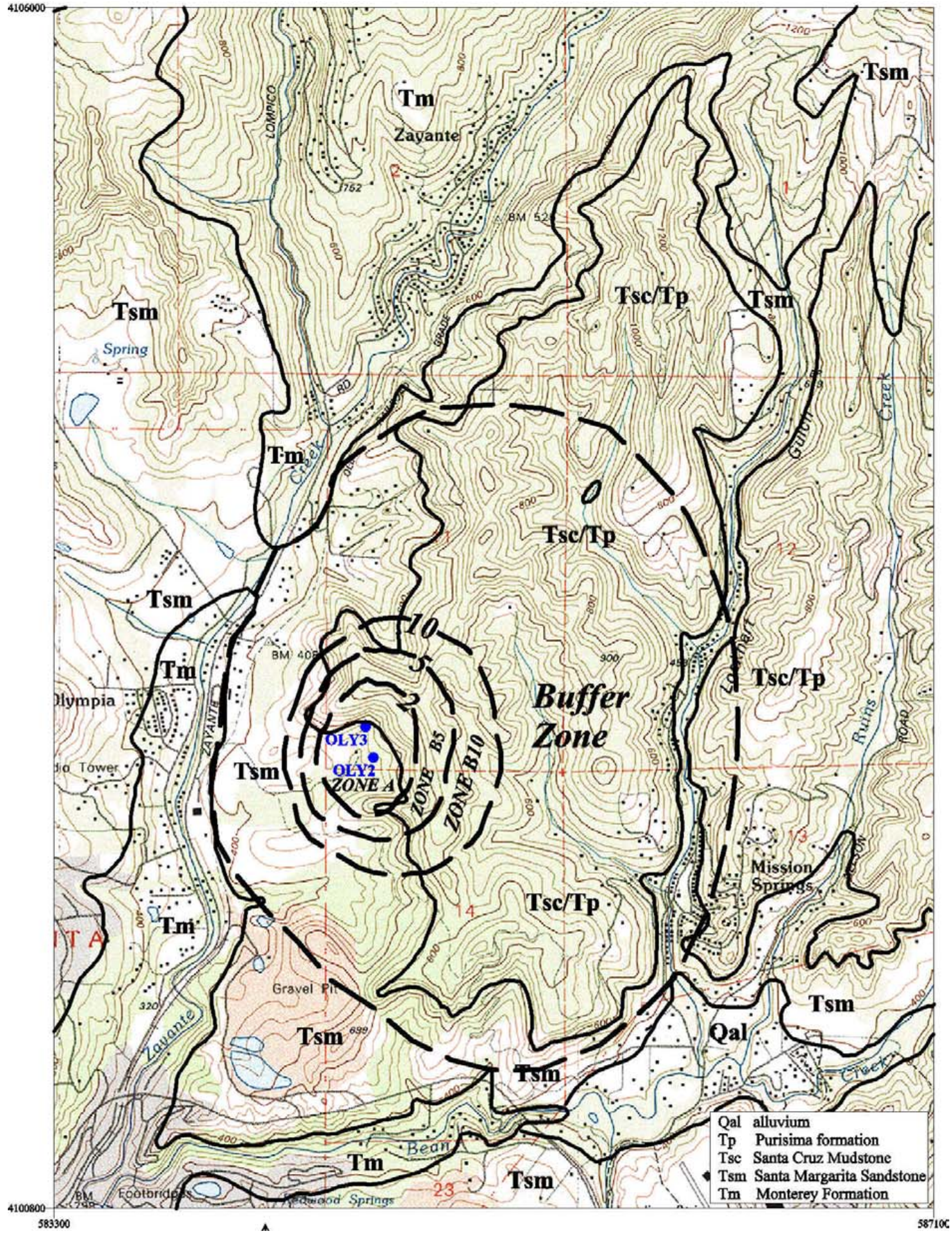
Herbert 2006

The Olympia quarry serves as a stormwater retention basin that receives stormwater and recharges the aquifer. Where the aquifer is exposed to surface, it has a high percolation capacity.

Figure 3. 5 shows the recharge area and protection zones for the Olympia well field. The protection zones are delineated by a District consultant (Johnson, 2005), following Department of Health Services (DHS) guidelines (California Department of Health Services, 1999) for preparing the Drinking Water Source Assessment (DWSAP). DHS considers these protection zones as critical for wellhead protection. Zones A, B5, and B10 are areas within which ground water is estimated to travel to the well within 2, 5, and 10 years, respectively.

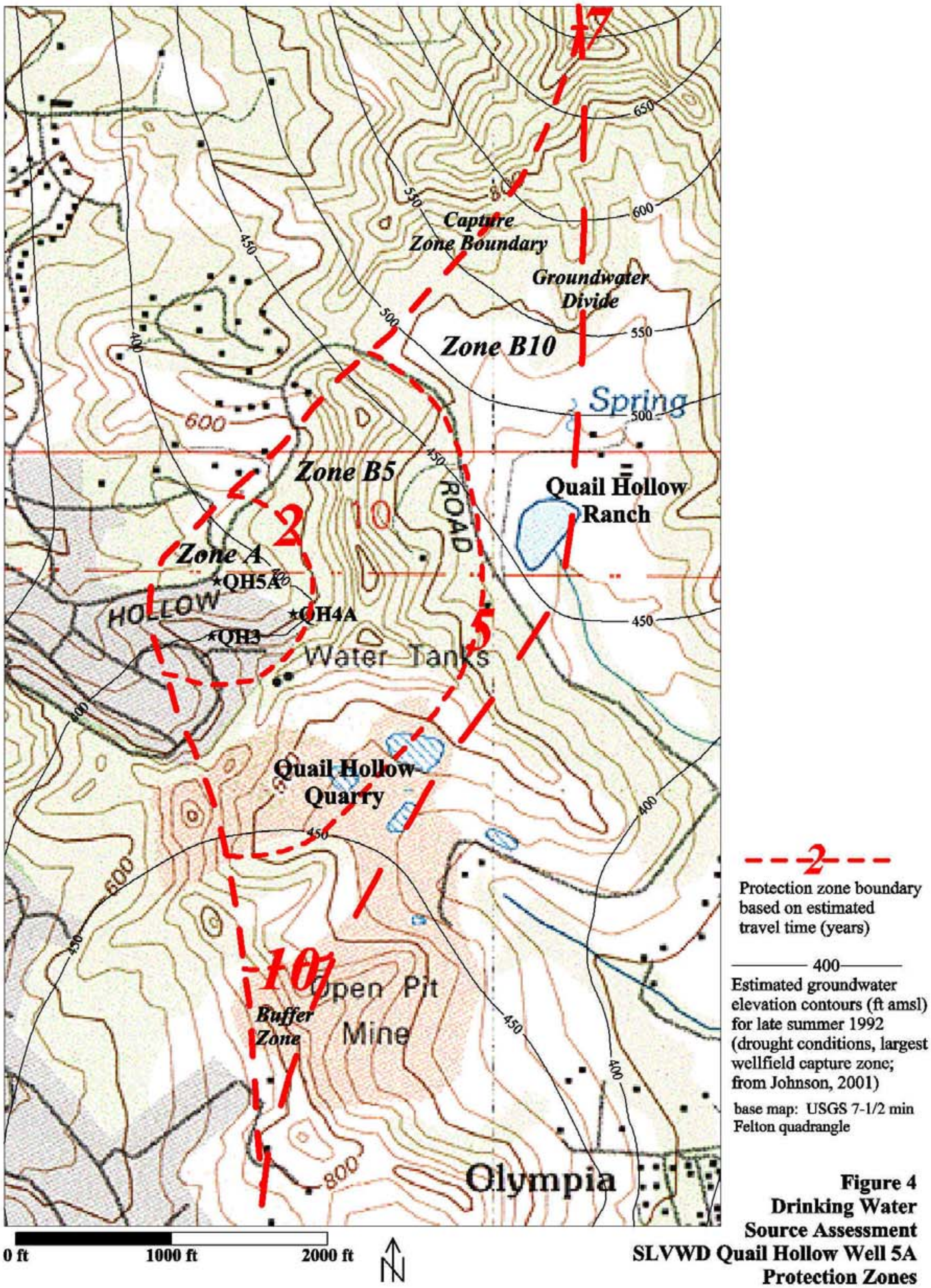
Similarly, Figures 3.6 and 3.7 show the recharge area and protection zones for Quail Hollow Well 5A and 4A, respectively. The Quail Hollow area is approximately 3 square miles, lying between Zayante and Newell Creeks and the San Lorenzo River, located east and southeast of Ben Lomond. The District wells' primary recharge area is 200 acres or more, depending on water table conditions. Land use in the recharge area includes residential, undeveloped chaparral and parkland, and sand quarrying. Because of the high permeability of the soils and sandstone, the potential for groundwater contamination for spills is significant.

Figure 3.5. Recharge area for the Olympia well field



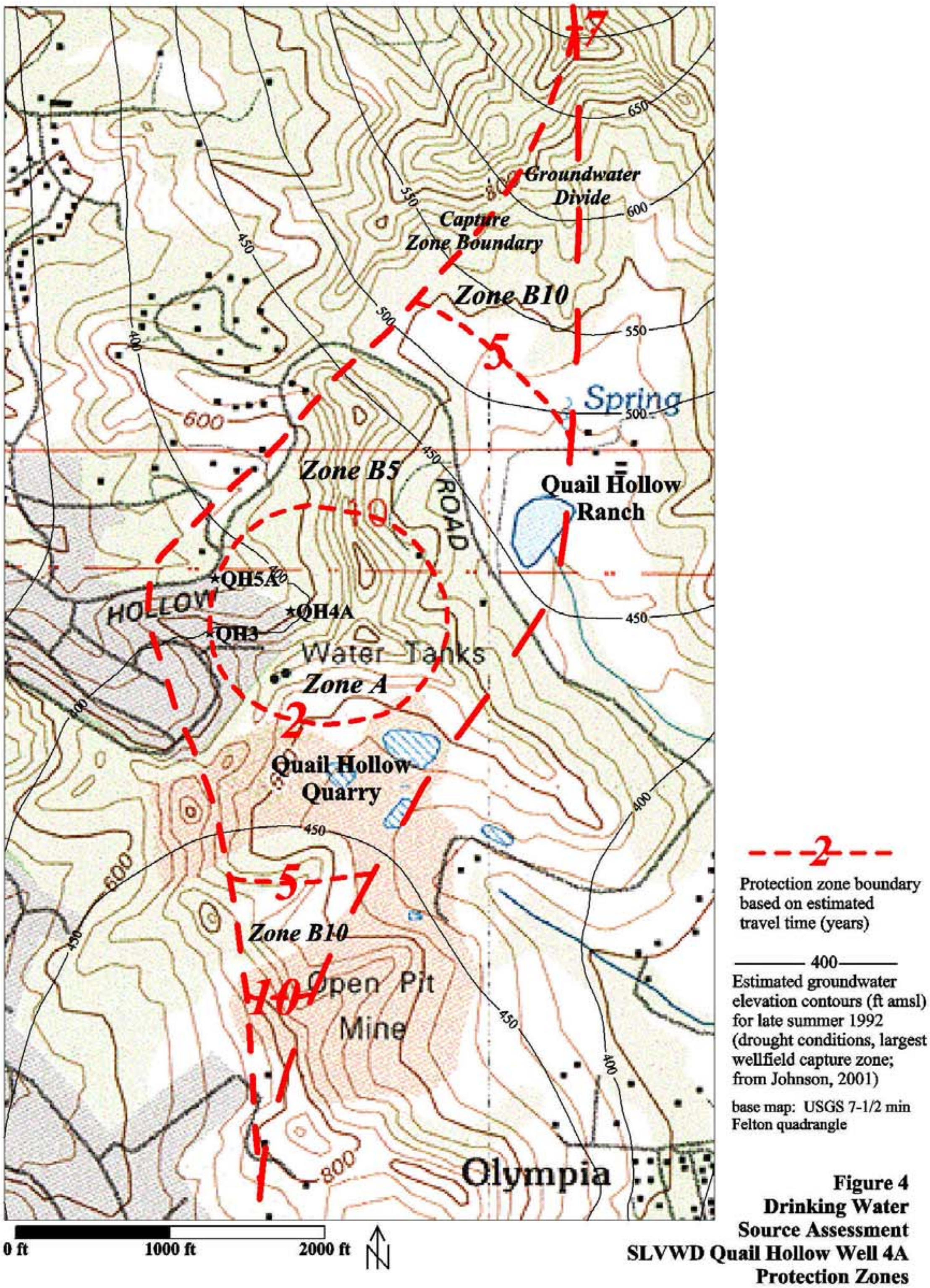
Source: Johnson, 2002.

Figure 3.6. Quail Hollow well 5A recharge area



Source: Johnson, 2001.

Figure 3.7 Quail Hollow well 4A recharge area



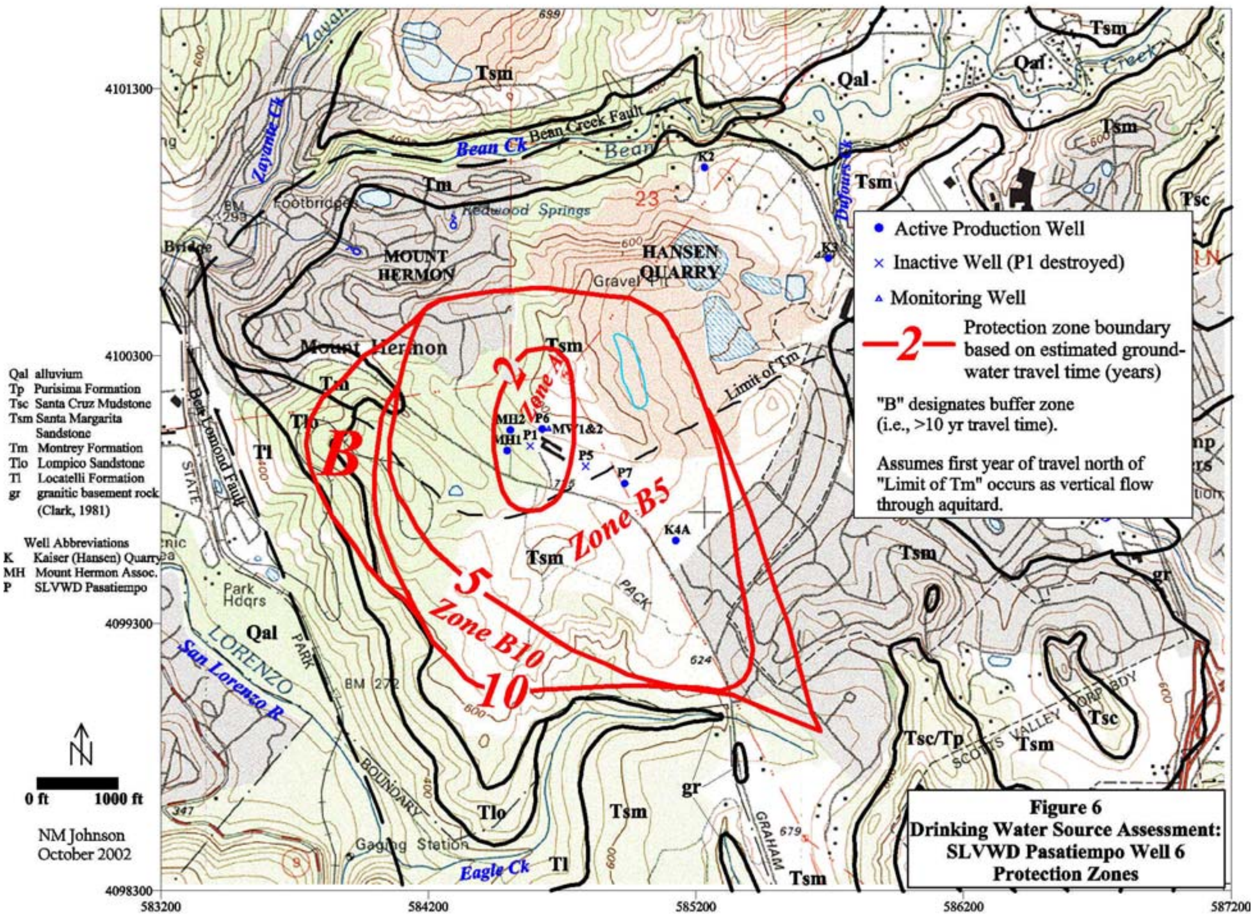
Source: Johnson, 2001.

3.2.5.b The southern service area

The District's southern service area consists of approximately 425 acres overlapping southwestern Scotts Valley. The District has approximately 670 connections in this area for which it produces an average of approximately 400 acre-feet per year. The District currently supplies this area with its two active Pasatiempo wells, 6 and 7. These wells are located near the Santa Cruz County Probation Center.

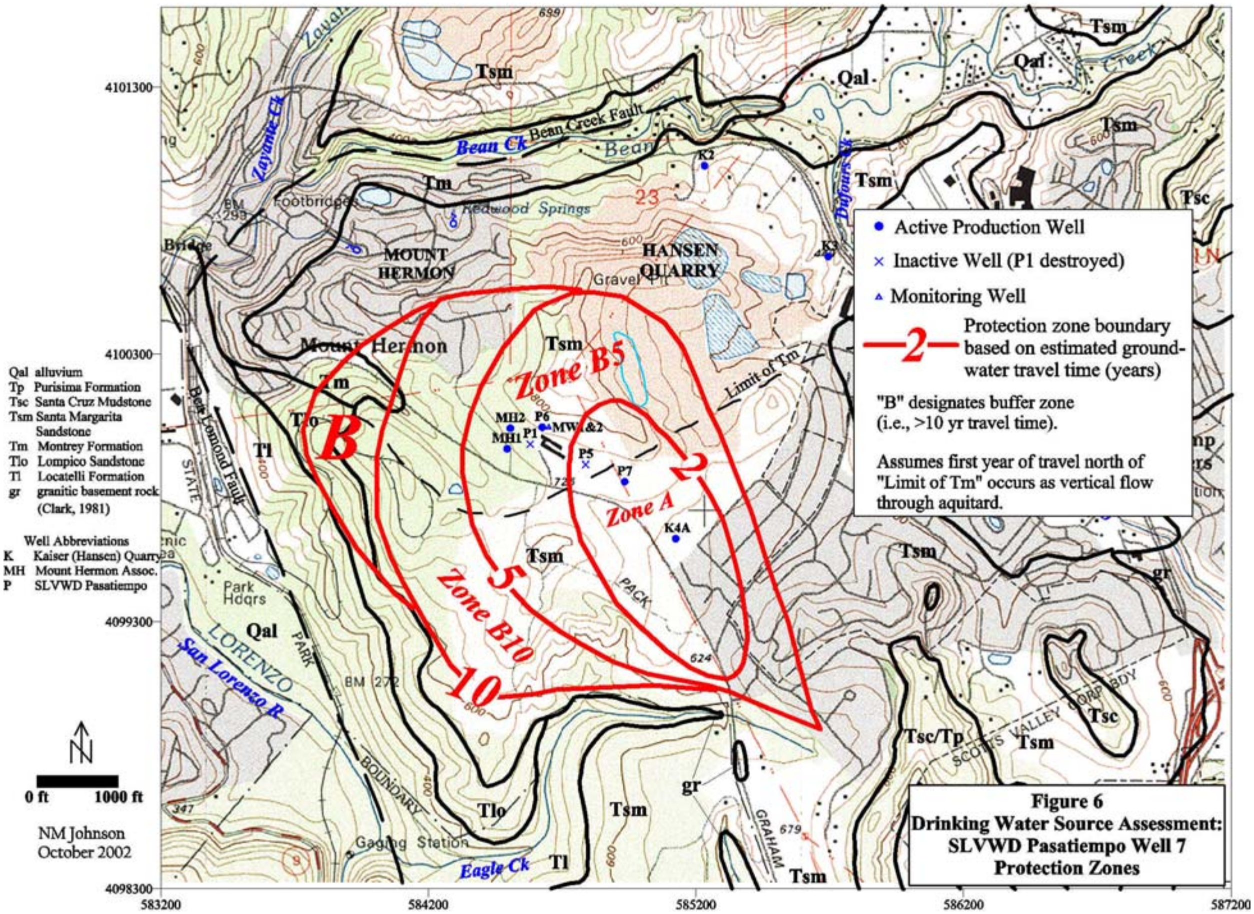
The District's Pasatiempo wells 6 and 7 are encompassed by a recharge area of slightly greater than 500 acres, as shown in Figures 3-8 and 3-9. Supply wells for Mount Hermon Association and Hansen Quarry also lie within this recharge area. Land use in the recharge area includes the mostly undeveloped probation center property, Henry Cowell State Park and Roaring Camp recreational areas, sand quarrying, portions of the unincorporated Mount Hermon residential area, and a residential area both within and outside the southwestern city limits of Scotts Valley.

Figure 3.8. Recharge area for Pasatiempo well 6.



Source: Johnson, 2002.

Figure 3.9. Recharge area for Pasatiempo well 7.



Source: Johnson, 2002.

3.2.5.c Mañana Woods

The Mañana Woods system provides water service to approximately 113 homes in the unincorporated Mañana Woods area southwest of Mt. Hermon Road, Scotts Valley, and three adjacent homes within the Scotts Valley city limit. The service area's only water source is a well located on Kings Village Drive approximately ½ mile from Mañana Woods. The water is treated at the site and pumped via mains to storage tanks within the service area.

In 2006, the SLVWD annexed the Mañana Woods area and the Mañana Woods Mutual Water Company. The annexation followed many years of the mutual water company dealing with hydrocarbons in its well water, litigation with oil companies, and a March 2005 agreement between the mutual water company, the SLVWD, and the oil companies to pursue this annexation. Petroleum hydrocarbon and gasoline additives including BTEX, 1, 2-DCA and MTBE were detected in ground water beneath and downgradient from four gasoline service stations located at the intersection of Mount Hermon Road and Scotts Valley Drive. The site, consisting of four service stations, has been a Regional Board lead groundwater investigation and cleanup case since 1989 (CCRWQCB, 2003).

In 2004, the oil companies treated the well and installed a new water treatment plant that effectively removes target hydrocarbon contaminants to a 'non-detection' level.

The District now operates and manages of all aspects of water service, and has installed meters.

3.3 Soils, geology, and hillslope geomorphology

This section discusses the soils, geology, and hillslope geomorphology of the San Lorenzo River watershed. The watershed is characterized by steep, rugged topography, with relatively high annual rainfall and episodic storm events. These factors combine to give the watershed a high natural background erosion rate (County of Santa Cruz, 2001).

3.3.1 Soils

Soil is the unconsolidated material found on the surface of the earth consisting of minerals, organic material, water, air, and organisms (mostly microscopic). Soil is capable of supporting plant growth, and is normally required for same. Individual soil particles vary greatly in size. The smallest ones (<0.002 mm) are called clay particles and the largest ones are called sand particles (.05 – 2.0 mm). In-between in size are silt particles. The relative proportion of sand, silt, and clay in a soil determines the "texture" of the soil, i.e., sandy, clayey, etc. A soil with a somewhat similar volume of sand, silt, and clay in it is referred to as "loam", or as having a loamy texture.

Soil is, arguably, the most important natural resource. Soil facilitates plant growth which provides food, wood for shelter, clothing, and other materials essential for human life. Soil supports wildlife populations by promoting vegetation that provides wildlife habitat. Soils store organic and inorganic chemicals, and provides habitat for microbes which decompose or degrade dead organic material and human waste. Soil acts to filter and purify water as occurs when water percolates through a healthy forest soil. Soil also stores some of the water from rainfall and slowly releases it into streams of springs during the dry season, thereby reducing flooding and supplementing water levels for fish. Soil microbes and soil organic matter can lock-up or break down many toxic chemicals, and make them unavailable for uptake. The organic matter in soil can provide long-term carbon sequestration that will reduce global warming. Lastly, soil serves as the structural material that supports buildings, roadways, and other structures necessary for modern society.

Sand particles can be up to 1000 times larger than clay particles. Consequently, the relative composition of sand, silt, and clay in a soil greatly determines soil physical properties such as drainage, water storage, aeration, and nutrient-holding capacity. A soil that is not dominated by either sand or clay particles, as for example a loamy soil, usually has the best physical properties. Some soils also contain a plentiful quantity of rock fragments and pebbles. Pebbles are small pieces of rock larger than a sand particle but less than 75mm in diameter. If the soil has more than 15 % pebbles by volume, the soil textural name includes the adjective, "gravelly," as in, for example, "gravelly loam."

Five factors interact over long periods of time to form soils. These are climate, geology (i.e., parent material), vegetation, soil organisms, and topography. It is important to note that geology is only one of the soil-forming factors. In Santa Cruz County the same geologic formation may be associated with several different soil series. Also, the same soil series may occur on several different geologic formations.

Soils form from both the decay of organic material and the weathering of underlying rock or parent material. As soils form they increase in depth and the action of rainwater seeping through the soil moves clay particles and certain chemical compounds downward, resulting in the formation of layers in the soil. These layers are called soil "horizons". It is the sequence, depth, and composition of these soil horizons that allow soil scientists to distinguish one type of soil from another.

One can think of soil as if it were a slice of layer cake. The icing on top represents the litter layer, also referred to as the *organic layer*. It is composed of needles, leaves, twigs, small branches, cones, etc. The organic layer does not contain sand, silt, or clay particles, so it is technically not soil, but it is acted on by soil invertebrates that slice, dice, and degrade it until it is small enough to be incorporated into the soil. The organic layer also provides numerous benefits to the forest, such as controlling erosion, maximizing the infiltration of rainwater into the ground, and allowing the formation of a humus-rich topsoil, which is high in its ability to hold nutrients and water for plant growth.

The first baked layer of the cake would be equivalent to the topsoil layer or “A” horizon. The greatest amount of soil nutrients, organic matter, and beneficial soil microbes are found in the “A” horizon. Consequently, the “A” horizon is the most fertile layer of the soil and roots from trees and other plants tend to concentrate in this layer. Below the “A” horizon is the “B” horizon which is often composed of finer textured soil particles. The lowest horizon is a layer of rock or other geologic deposit, and is referred to as the “C” horizon. Each of these horizons is routinely divided into further divisions, or sub-horizons. The sequence of soil horizons from the surface to bedrock or a depth of 6 feet is called the *soil profile*. It is the thickness, sequence, and composition of soil horizons in the soil profile that define a specific *soil series*. Soil series are named for the geographic location where that specific profile was first seen, and the texture of the “A” horizon. For example, the Ben Lomond Sandy Loam soil is a soil first described near Ben Lomond having a sandy loam texture in the “A” horizon. A sub-agency of the U.S. Department of Agriculture called the Natural Resources Conservation Service (formerly called the Soil Conservation Service) identifies, names, and maps the different types of soils and provides guidance in soil management.

3.3.1.a Soil diversity in the San Lorenzo River watershed

The distribution of soils in the watershed is complex because of the large number of soil series that are present in a relatively small area, and because the soil series often occur in small areas that are closely inter-mixed with other series throughout the watershed (U.S. Soil Conservation Service, 1980; Estrada and Singer, 1978; Estrada, 1976). The Natural Resources Conservation Service identified 24 different soil series in the San Lorenzo River watershed and produced a soil survey map showing the presence of approximately 54 different soil mapping units[1]. This map can be viewed on the internet at www.ca.nrcs.usda.gov/mlra02/stcruz.html. These soils range from deep, fertile soils (such as Ben Lomond Sandy Loam, Nisene Loam) to thin, rocky and infertile soils (such as Maymen Stony Loam, Bonny Doon Loam). Some soils are excessively well-drained and droughty (such as Zayante Coarse Sand) and some are poorly drained with a seasonal high water table (such as Watsonville Loam).

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[1] A soil mapping unit consists of several soil series mapped together in a specific slope category and named after the most common series present. Since soil survey maps delineate soil mapping units and not individual soil series, one must physically examine the soil profile in the field to determine which of the series found in the soil mapping unit is the one present at any given location.

Most soils in the San Lorenzo River watershed have developed under forest, woodland, or chaparral. About 75 percent of the watershed is covered by redwood-Douglas-fir forest or mixed evergreen forest. Some of the most productive soils for the growth of forest trees are Ben Lomond Sandy Loam, Felton Sandy Loam, Aptos Loam, Nisene Loam, and Lompico Loam. These soils typically have a one to several inches thick litter layer of leaves, twigs, cones, and needles on the surface. The organic matter in the litter layer is decomposed by soil organisms and incorporated in the underlying “A” horizon, giving it a dark color, relatively high porosity, and a good soil structure. The transition zone between the duff layer and the underlying soil is especially rich in plant nutrients and is extensively exploited by fine roots and beneficial soil fungi, called *mycorrhizae*, which form a symbiotic relationship with plant roots.

Some individual tree species within forest or woodland have profound effects on the soil that develops underneath their canopy. These effects are not considered in published soil surveys. Redwood litter is known to promote water infiltration in underlying soils. Bay (*Umbellularia californica*) litter has been observed to have the opposite effect. Soils formed under bay trees have been observed to have a reduced infiltration rate, a lower porosity, and a less favorable soil structure (Singer, 2004). Bay leaves release toxic chemicals that suppress the germination or growth of herbaceous plants and are toxic to insects (Corelli, 2005). Their slow rate of decompositions suggests that they are also toxic to many soil micro-organisms. Consequently, stands of bay trees on steep slopes have little or no litter layer and are extremely susceptible to surface erosion and dry ravel (Singer, pers. obs.).

Chaparral covers about 12 percent of the watershed, and is primarily found on ridgetops and the upper part of south-facing slopes. The soil most commonly associated with chaparral is Maymen stony loam. This soil averages only 14 inches deep and contains many stones and rock fragments throughout its profile. It has formed in material derived from sandstone, shale, or granitic rocks.

Only a few soils in the watershed have conditions that are not favorable for plant growth or for other human uses. Those watershed soils that are shallow, infertile, droughty, or have drainage problems are listed in Table 3-3 below. Soils that are shallow or have slow subsurface percolation rates are generally unsuitable for use as septic tank leach fields.

Table 3-3. Problem soil series in the San Lorenzo River watershed

Soil Condition	Soils That Are Too Sandy	Soils That Are Too Shallow (< 15" deep)	Soils With Too Slow of a Subsurface Percolation Rate (< 0.2"/hr)
Soil Name	Zayante Coarse Sand	Bonny Doon Loam Maymen Stony Loam	Cropley Silty Clay Danville Loam Diablo Clay Lompico Variant Loam Los Osos Loam Tierra Sandy Loam Watsonville Loam
Landform Type	Inland marine sand deposits, developed atop Santa Margarita Sandstone	Upland areas	Upland areas, marine terraces, and old alluvial fans. Cropley and Diablo soils are of very limited extent with Cropley found on younger alluvium.
Problems for Human Use	* Infertile * Droughty * Highly erosive * Unsuited for septic leachfields (perc. rate is rapid)	* Droughty * Unsuited for septic leachfields (inadequate soil depth)	* Seasonal high-water table * High rainfall runoff * Unsuited for septic leachfields (perc. rate is too slow)

Source: Singer, 2008

The most common soil series that occur in the watershed are not listed in Table 3-3, and they include Aptos Loam, Ben Lomond Sandy Loam, Catelli Sandy Loam, Lompico Loam, Elder Sandy Loam, Elkhorn Sandy Loam, Lompico Loam, Madonna Loam, Nisene Loam, and Sur Stony Sandy Loam. Less common watershed soils not listed in Table 3-3 are Baywood Loamy Sand, Pfeiffer Gravelly Sandy Loam, Santa Lucia Shaly Clay Loam, and Soquel Loam.

Neither high salinity nor excessive levels of toxic trace metals are known to occur in the San Lorenzo River Watershed soils with the exception of cadmium.

3.3.1.b High-cadmium soils

Some soils and river sediments have extremely high levels of cadmium. Cadmium is a naturally-occurring trace element that can be toxic to fish, wildlife, and humans, contributing to diseases of the kidney, liver, and skeletal system (CIWMB, 1998). Domesticated animals are also subject to cadmium poisoning, and horses may be especially sensitive (Piscator, 1985). The typical concentration of cadmium in U.S. soils is low, ranging from 0.1 to 1.0 parts per million (ppm) (Page et al., 1987). Many plants are relatively unaffected by cadmium, and some species will concentrate it in high levels in their plant tissue. Food or forage plants grown on soils with high cadmium levels can accumulate it to the extent that they are unsafe for repeated and regular consumption. Leafy vegetable crops (lettuce, Swiss chard, and spinach) are the most efficient concentrators of cadmium (Page et al., 1987).

It is important to note that the District routinely monitors its ground and surface water sources for cadmium, as required by the California Department of Public Health (CDPH). To date, no detectable levels of cadmium have been found (Busa, 2008).

High cadmium levels in food can put humans or animals at risk of cadmium-poisoning if those foods are eaten on a regular basis over a number of years. The U.S. Food and Drug Administration has limited cadmium levels in artificial food colors, which are ingested in only small quantities, to 15 ppm (U.S. ATSDR, 1999). Lettuce and Swiss chard from local areas within the San Lorenzo River watershed have had cadmium concentrations above 30 ppm and one reported value of 55 ppm (Golling, 1983). The source of the plant-absorbed cadmium is soil formed on bedrock or sediment from the geologic strata collectively known as the Monterey formation. Soils associated with the Monterey formation in California are known to have the highest known natural concentrations of cadmium, up to 22 ppm (Page et al., 1987). Some soils that developed from the Monterey Formation in the San Lorenzo River watershed have cadmium values of 5.0 to 6.5 ppm. (Golling, 1983). These soils have not been linked to any one particular soil series, as several different soils may form on the Monterey formation or its sediments and levels of cadmium within the Monterey formation are variable.

Despite the high cadmium levels found locally in leafy vegetables, there have been no publicized local reports of human cadmium poisoning. This may be because the absorption of cadmium in the intestines is only poorly understood. Concurrent ingestion of certain other substances, including zinc, iron, and calcium may block or reduce the absorption of cadmium (Reeves et al., 2005).

A more serious concern may be potential cadmium poisoning of wildlife. Since cadmium levels in organisms increase as one moves up the food chain through the process known as bio-magnification, top-level predators may end up with a debilitating body burden of cadmium. Animals that browse extensively on cadmium accumulator plants, like willows, might also be subject to cadmium poisoning (Larison et al., 2000). Since no studies have been conducted on the effects of cadmium on animals in the San Lorenzo River watershed, no definitive conclusions can be reached. However, it would be prudent for land managers to be cautious about introducing cadmium into the food chain, as they might do inadvertently by placing fill material excavated from roadcuts or construction sites in the Monterey Formation or sediments dredged from the river or local reservoirs onto the ground surface where they can be colonized by willows or other cadmium accumulators.

Some soil management techniques exist that can be used to reduce cadmium levels in crops grown on high-cadmium soils. Maintaining high levels of soil organic matter and keeping the soil pH level above 7.0 will decrease cadmium uptake by plants (Golling, 1983). Alternatively, cadmium-accumulator plants, such as some species of willow, can, when coppiced, be used to reduce cadmium levels in the soil through repeated harvesting and safe disposal of the plant biomass before leaf fall (Dickinson, 2005).

3.3.2 Geologic areas and soil types of the San Lorenzo River watershed

The three distinct geologic areas of the watershed were formed by movement along local fault zones, as shown in Figure 3.10. These geologic areas are characterized by different soil types. Erosion rates vary in different areas of the watershed, depending on soil types, as shown in Table 3.4.

A brief description of the geologic areas and their soil types follows.

3.3.2.a Area 1: Ben Lomond Mountain geologic unit.

This area lies west of the Ben Lomond Fault and south of the Zayante Fault, Ben Lomond Mountain. This geologic unit includes the steep eastern slope of Ben Lomond Mountain, which supplies all of the District's surface water. Ben Lomond Mountain was formed by movement along the Ben Lomond Fault. The uplifted hard, crystalline rock formed Ben Lomond Mountain, the southwestern edge of the watershed. Principle subwatersheds of the San Lorenzo River draining Ben Lomond Mountain include Fall, Bull, Alba, Malosky, Clear, Sweetwater, Peavine, Jamison, and lower Boulder Creek with its tributaries.

Soil types: The uplifted mass of basement bedrock is predominated by granites of various degrees of weathering, schists and marble (locally known as limestone). A thin soil layer covers the very steep slopes of the drainages supporting dense coniferous and mixed evergreen forest. In areas of the Pacific Northwest, decomposed granite is the parent material of highest concern for erosion (Spence et al., 1996). Here, decomposed granite is the least prone to erosion, relative to other substrates within the San Lorenzo River watershed.

Streams in this area generally have good levels of boulders and cobbles, are free of silt, and clear very quickly after storms. There is generally adequate summer low flow to support diverse aquatic habitat, as well as to supply water purveyors. The lower portions of these watersheds are composed of Tertiary sandstone and mudstone. Figure 3.11 shows a composite stratigraphy of these formations. These lower portions are more susceptible to landsliding and erosion, especially when disturbed. The lower gradient portions of these watersheds still support steelhead and historically supported coho salmon.

Table 3.4. Characteristics and erosional variables of geologic units in the San Lorenzo River watershed.

Name	Geology	General Character	Remarks
Quaternary Alluvium	Coarse – to fine-grained river and marine terrace deposits.	Poorly sorted and loosely consolidated sands and mudstones.	These deposits include all of the marine terrace, river terrace and floodplain accumulations. They are locally discontinuous, not heavily vegetated, moderately stable deposits that show very little landsliding or creep.
Purisima Formation	Medium to very fine-grained sandstone and a fairly common dark-gray silty mudstone (Cummings, Touring, and Brabb, 1962, p. 197)	Massive and poorly bedded or locally cross-bedded.	The fine-grained nature of this formation makes it a potentially large contributor of fine sediment. However, heavy vegetation and generally shallow slope make this one of the more stable substrates. Moderate to low amount of rockfall and landsliding.
Santa Cruz Mudstone	Slightly siliceous organic mudstone (Clark, 1966, p. 133)	Medium to thick=bedded; lacks a distinct fissility.	When severely disturbed this formation acts as a source of fine sediment. In general, it is heavily vegetated and occurs on steep slopes. This formation acts as a protective cover for the underlying Santa Margarita Sandstone. Erosion and quarrying of the underlying formation has produced over-steepened slopes. A moderate amount of landsliding occurs on this unit.
Santa Margarita Sandstone	Moderately sorted, arkosic sandstone. Poorly consolidated and medium-grained with occasional fossil shell hash beds.	Thick-bedded to massive. Steep, thick cross-beds.	This formation is highly susceptible to erosion. Disturbance produces a rapid and severe erosional response. Exposures are subject to both wind and fluvial erosion and act as significant source of medium-grained material. Soils that develop on the sandstone have a thin, encrusting surface layer that cements the sands and prevents removal. Disruption of this layer, either by vehicle traffic or foot traffic, enhances erosion severely.
Monterey Shale	Mudstone. High content of organic mater and discontinuous laminae of clastic material (Clark, 1966, p. 97	Medium- to thick-bedded, irregularly laminated and decomposes into porcelaneous debris.	Resistant formation that forms heavily vegetated, steep slopes whose erosional response is minimal.
Lompico Sandstone	Medium- to fine-grained sandstone. Light gray to yellowish gray; weathers buff (Clark, 1966, p. 80)	Moderately- to well-sorted, thick bedded to massive loosely consolidated sands.	This unit is highly prone to slumping and debris slides. Poorly vegetated in some areas. Shows incipient gullying on numerous, steeper slopes. Occasionally forms steep cliffs. Exposures along Zayante Fault are severely deformed and show a rapid erosional response to disturbance.
Lambert Shale	Organic mudstone with local, thin interbeds of fine sands.	Thin- to medium-bedded; decomposes into friable blocks and fine, easily transported particles.	Steep exposures in road cuts and stream banks show numerous small slumps. May be a source of fine sediment. Shows a moderate response to disturbance. Volumetrically insignificant.

(Continued on next page)

Table 3.4 Characteristics and erosional variables of geologic units in the San Lorenzo River watershed (continued).

Vaqueros Sandstone	Moderately sorted, very fine to medium-grained sandstones with numerous interbeds of mudstone (Brabb, 1960, p. 58)	Laminated to very thick-bedded; complexly fractured; decomposes into friable, easily transportable blocks and fine particles.	This formation is one of the principal contributors of sediment in the Watershed. The heterogeneous nature of the rock types produces variable erosional responses. Some areas are underlain by mudstones and siltstones and are highly prone to sliding. Some localities underlain by interbedded siltstone and sandstone show large block glides on dip slopes. Other localities are underlain by loosely consolidated sands that respond to disturbance in much the same manner as the Santa Margarita Sandstones. The overall response to disturbance is high.
Zayante Sandstone	Heterogeneous sequence of interbedded pebbly sandstone, conglomerate, and sandy siltstone (Clark, 1966, p. 45)	Thick- to very thick-bedded; decomposes into friable, coarse particles.	Potentially significant source of coarse material. Severely disturbed in the Zayante Creek and Lompico Creek drainages. Forms debris slides and slumps. However, overall response is moderate to good.
Mindego Formation	Interstratified volcanic rocks with mudstones, shales, sandstones, conglomerates and carbonates.	Thin- to thick-bedded sedimentary rocks with interbedded massive submarine basaltic flows. Complexly fractured.	Exposures of this formation are limited in their extent. In general, this unit supports steep slopes, and moderate to sparse vegetation. Road cuts show rockfall and debris sliding. This formation weathers to produce fine material that is easily transported.
San Lorenzo Formation (Rices Mudstone and Two Bar Shale members)	Interbedded mudstones, siltstones and shales.	Massive to laminated, friable, decomposes into easily transported fine material. Produces clay soils.	Highly unstable unit. Erosional response to all types of disturbance is rapid and severe. Occurs on moderately vegetated, shallow slopes and is highly susceptible to landsliding and soil creep. Unimproved roads are prone to severe gulling and slumps along cut banks. This formation is one of the principal contributors of fine sediment in the Watershed.
Butano Sandstone	Interbedded sandstones and siltstones.	Medium- to thick-bedded massive sands interbedded with siltstones and mudstones. Decomposes into friable, easily transported blocks.	This unit is generally associated with steep, unstable slopes. Interbedded massive sands and siltstones make hazardous dip slopes. Forms large talus slopes where extensively exposed. Soils are poorly developed and prone to debris sliding. Unimproved roads show marked instability.
Locatelli Formation	Interbedded medium sandstones and siltstones.	Massive, thick sands interbedded with thinly laminated siltstones and shales.	In the area of Jamison Creek, this unit produces moderately vegetated, very steep slopes of high stability. The thick sandstone units produce a strong substrate.
Cretaceous granitic rocks	Intrusive complex ranging from granite to gabbro.	Mostly medium-grained quartz dirite. Deeply weathered in some localities, producing thick, coarse-grained soils.	Produces very steep, heavily vegetated slopes of high stability. In areas of intense weathering, disturbed slopes show extensive gullying. In general, this unit responds to disturbance well.
Metasedimentary rocks	Interstratified marbles and biotite schists.	Schistose rocks with varying amounts of quartz, plagioclase, cordierite, biotie and sillimaite.	This unit produces varying slopes and vegetative cover with moderate to high stability. The overlying soils are fairly well developed and stable. The erosional responses to disturbance is moderate to good.

Source: Mount, 1977.

3.3.2.b Area 2: East of the Ben Lomond Fault and south of the Zayante Fault.

As shown in Figure 3.10, the principle watersheds in Area 2 include Love Creek, Newell Creek below the reservoir; lower Lompico Creek, Zayante and Bean Creeks; Carbonera Creek, Branciforte Creek; the Quail Hollow area; Mount Hermon, Scotts Valley, Graham Hill and Henry Cowell areas.

Soil types: This area is predominated by sandstones and shales forming highly erosive soils that are sand or clay rich. These atypical soils have given rise to very rare and unusual associations of trees and plants such as sandhills communities. Many species found within these sand ecological communities are completely disjunct from their usual areas, and many species are endemic or locally rare. Due to weak cementation, erosion rates are naturally high in this area, especially where sandy soils occur in steep headwater areas or near channels. The Santa Margarita and Lompico aquifers are recharged through the sandy soils. These aquifers not only provide valuable summer base flows to streams of the eastern watershed including the mainstem San Lorenzo River, but also provide the water supply for most of the watershed. Levels of recharge also directly affect groundwater quality. Recharge rates have been drastically reduced due to high densities of impermeable surfaces related to development. The sandy areas have the relatively lowest topographic gradient, high density of land use disturbances, including equestrian facilities, trails, surface mining, residential, commercial, and industrial uses. The sandy soils which were capable of absorbing nearly all of the rainfall under natural conditions now form steep-walled gullies and gulches due to increased runoff from paved and covered surfaces and due to soil disturbance. Roads and homes are the predominant sources of sediment. Large landslides and many small ones, often at the stream margin, chronically feed sediment into stream systems. High levels of erosion chronically feed streams with sediment, filling pools and embedding valuable habitat within all reaches down stream. The erodibility of the mudstone units in the Monterey and Santa Cruz Mudstone Formations within this area can vary considerably.

3.3.2.c Area 3: North of the Zayante Fault

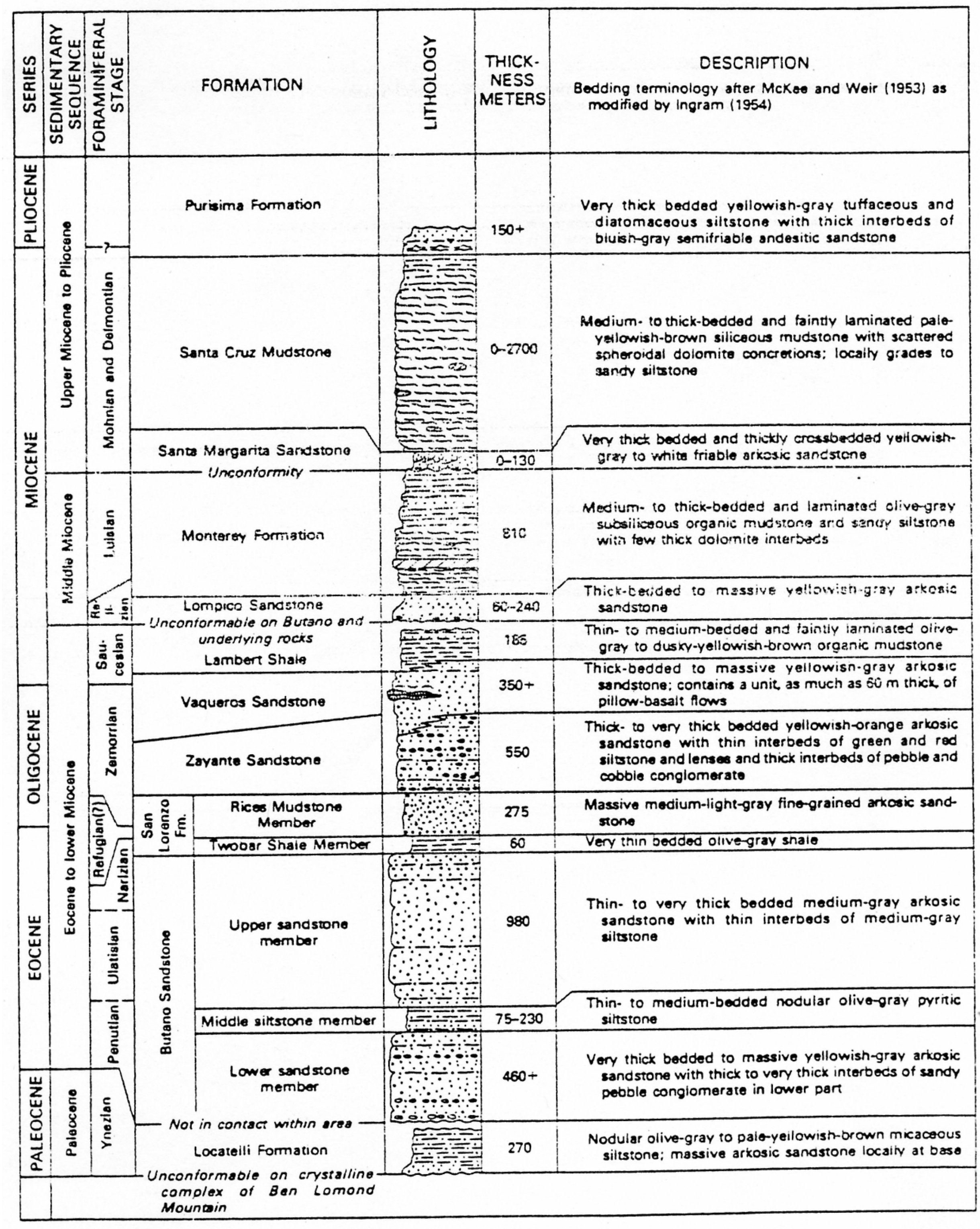
As shown in Figure 3.10, the principle watersheds in Area 3 include the upper San Lorenzo River (above Boulder Creek); Kings, Two Bar, and Bear Creeks, tributaries to the San Lorenzo River; plus the northern portions of the Boulder, Zayante, Lompico, Newell, and Bean Creeks. This area extends from the Zayante Fault to the western and eastern "skyline" of the Santa Cruz Mountains, which form the northern boundary of the watershed.

Soil types: This area's steeply inclined, dipping and folded strata are comprised of Tertiary Period marine deposits of interbedded sandstones, shales, and mudstone. Soil from these formations is a complex mosaic of coarse-grained loams, ranging from less than a foot deep to deep, organic, rich, sandy loam on valley terraces. This mosaic of soils gives rise to patchy diverse vegetation types and a varying erosiveness. Slopes tend to be steep and prone to moderate to severe erosion, especially where disturbed. The Butano Fault runs across this northern area but does not divide the upper half distinctly in geologic terms. Steep slopes associated with the Butano Fault are especially prone to erosion from roadcuts and land disturbance. Disturbance erosion in this area continually provides easily moved sediment to the watershed. Many of these streams drain steep gradient areas and deliver high sediment yields to downstream reaches. Dry-season flows are generally lowest in this geologic terrain, with streams often drying to isolated pools during summers of dry years. Periods of low summer flows exacerbate impacts from sedimentation on aquatic habitat and domestic water.

Figure 3.10 Geologic areas and major fault zones of the San Lorenzo River watershed.

(11 x 17 color foldout)

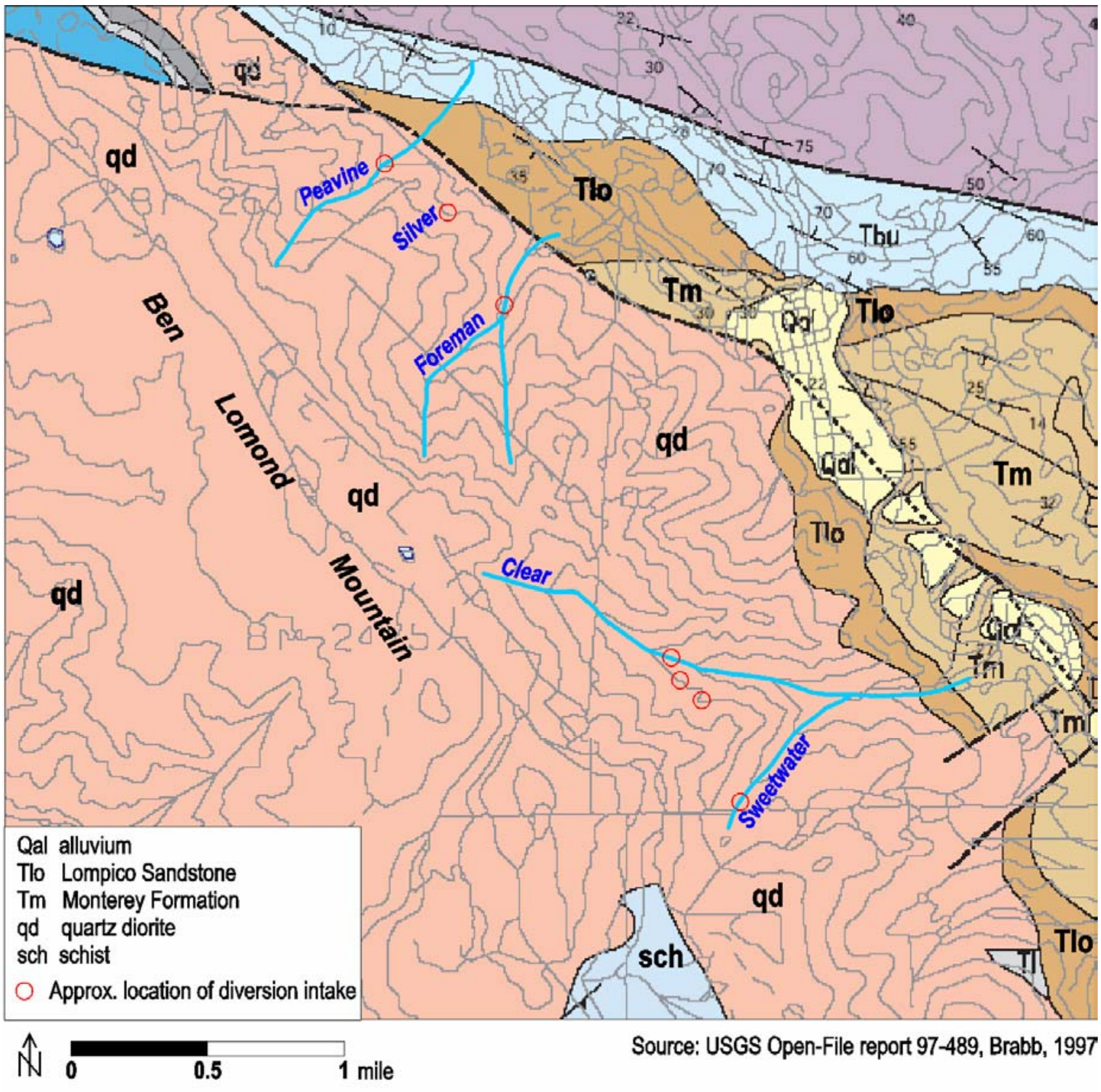
Figure 3.11. Composite stratigraphic section of tertiary rocks of the central Santa Cruz Mountains northeast of San Gregorio fault.



Source: Clark, J. C. 1981.

Figure 3.12 shows the geology of the District's stream diversion watersheds on Ben Lomond Mountain.

Figure 3.12 Geology of the District's stream diversion watersheds



3.3.3 Hillslope geomorphology

Geomorphic processes involve the process of erosion, as soil becomes detached and is transported by water, wind, or gravity. Erosion can be attributed to the underlying geology, seismic or geologic activity, steepness of slopes, climate, vegetation, and land use.

3.3.3.a Soil erosion

Soil erosion is a three-step process consisting of the detachment of a soil particle, its movement down slope, and its deposition in a channel, floodplain, or flatter portion of the slope. The ease of detachment is largely controlled by the following four physical factors: (1) the length and steepness of slope, (2) the amount of vegetation or litter layer cover, (3) soil conditions (texture, degree of compaction or soil aggregation), and (4) rainfall intensity.

Because of the steep slopes, high rainfall intensity, and prevalence of land use activities that disrupt soil cover on watershed lands, the rate of soil erosion in the San Lorenzo River watershed is high.

There are three types of surface erosion – sheet erosion, rill erosion, and gully erosion.

Sheet erosion is the detachment and movement of soil particles due to raindrop impact and sheet flow of rain runoff. The result is the loss of a thin layer of soil that is virtually undetectable by eye. Over time the results of sheet erosion become clearly visible in the form of tree roots seemingly growing on top of the ground surface.

Rill erosion is the erosion of a series of narrow grooves cut into the surface. Sheet erosion usually progresses to rill erosion, which usually occurs on longer slopes or road surfaces. Both sheet and rill erosion are common on dirt roads and construction sites with bare soil and can result in significant soil losses. A soil loss equivalent to the thickness of a nickel over one acre constitutes a soil loss of 15 tons which is roughly equivalent to 15 cubic yards of sediment. Where signs of sheet erosion are visible, or where it has progressed to rill erosion, soil losses are more than 20 tons per acre per year – the equivalent of dropping two or more dump truck loads of soil into the stream.

Gully erosion is erosion that results from gully formation and subsequent growth in gully length, depth, and width. A gully is defined as a new channel, at least one foot square in cross-section that has been eroded by storm runoff. Rill erosion on long slopes will progress into gully formation. Gullies can most frequently be found in roadside ditches, below culvert outlets, or on roadbeds below obstructed culverts.

Sheet, rill, and gully erosion are the most prevalent form of erosion on unpaved roads and driveways, which in turn, are a major source of sediment in the San Lorenzo River Watershed (County of Santa Cruz, 2001).

Because of their sand texture, sparse vegetative cover, and lack of organic matter, Zayante Coarse Sand soils are the most erosive of all soils in the watershed when they are disturbed. In contrast, in their undisturbed state they have a very low erosion rate, probably due to their high infiltration rate which leaves little surface runoff to detach and transport soil particles. When water is concentrated in culverts, roof downspouts, or ditches and released onto Zayante soils, those same soils experience rapid and severe gully erosion.

The least erosive soils in the watershed would be all of those soils that occur within an undisturbed redwood/Douglas-fir forest on level or gently-sloping land.

3.3.3.b Erosion potential

Erosion potential is related to specific properties of soils or rock formations, the steepness of slopes, the volume and intensity of rainfall, and the impacts of human activities. The principal soil properties that facilitate erosion from precipitation or flowing water are detachability and transportability. Soil particles that are easily detached from the soil mass and easily transported by flowing water are most susceptible to erosion. Both detachability and transportability are related to soil or rock texture, particle size, and the degree of cementation between individual grains. For example, clay particles tend to adhere to each other and thus, are not readily detachable. Pebble-to-boulder size clasts (rock fragments) may be too large and heavy to be transported by flowing water, thus armoring the soil against further erosion. In contrast, uncemented ("friable") sand is highly erodible (Swanson Hydrology & Geomorphology, 2001).

Swanson Hydrology & Geomorphology (2001) suggests that the area south of the Zayante fault is more susceptible to surface erosion, while the area north of the Zayante fault is more prone to deep and large scale landslides. However, some sandstone formations north of the Zayante Fault are extremely erodible, once denuded.

Decomposed granite is one of the watershed's most stable geological substrates. Where exposed to weathering or erosion, geologic formations such as mudstones, shales, and less coherent sandstone units may be significant chronic sources of sediment (Hecht & Kittleson, 1998). This occurs more commonly in the steeper, upper watershed areas.

Hecht & Kittleson (1998) recognized four geologic formations in the watershed that are consistent sources of sediment loads to streams, despite stabilization efforts:

- Santa Margarita Sandstone along Bean Creek and neighboring drainages. Disturbance of the Zayante soils and weathered mantle results in severe gullying and long-term instability. The high permeability and low available water capacity and fertility in exposed Santa Margarita sandstone severely limit revegetation efforts, particularly in south-facing slopes.
- Vaqueros Sandstone, where disturbed by road development in upper Bear Creek and Deer Creek, and in the upper Boulder Creek, Zayante Creek, and Kings Creek drainages.
- Sandier parts of the Purisima and Lompico formation in Branciforte and Carbonera Creeks, particularly where residential development, roads, agricultural practices and livestock (primarily horses) concentrate flows or reduce capacity of the soils to hold moisture and attenuate runoff are also sources of landslides and winter debris.
- Mudstones in Kings Creek, Logan Creek, and the upper San Lorenzo River. Where exposed, vegetation is often naturally sparse, soils are thin or non-existent and weathering continuously exposes erosive surfaces. Steep slopes, unsurfaced roads, and roadcuts in these areas are notable sources of persistent turbidity, particularly where year-round road use is necessary for residential access.

Coats et al. (1982) found the two geologic formations that contributed the most sediment to the Zayante stream system from landsliding during the January 3-5, 1982 storm were the Vaqueros Sand Stone and the Butano Sand Stone. Moderate contributors were (in descending order) Lambert Shale, Santa Margarita Sand Stone, Monterey Shale, and Lompico Sandstone; with the Santa Margarita Sandstone and Monterey Shale having the highest representation in the survey areas. They also found that the relative contribution of sediment to the stream system from different geologic formations varied between sub-watersheds and depended largely upon steepness of slope, proximity to stream and disturbance (Coats et al., 1982).

Coats et al. (1982) found Vaquero, Butano, Zayante sandstone, and Monterey shale more resistant to streambank erosional processes than the Santa Margarita sandstone due to the greater degree of consolidation and cementation of the individual grains in the Vaquero, Butano and Zayante sandstones. The Monterey shale bedrock is even more resistant than the sandstones. Coats et al. (1982) further described landsliding in the watershed during the 1982 storm:

> The landslide mapping revealed that the most intense sliding occurred not in the headwaters of Zayante or Lockhart Creeks, where the area of steep slopes is greatest, but rather in areas of steep slopes along the middle portions of the creeks. Differences in bedrock geology cannot explain this observation, since both the same formations occur near the headwaters of Zayante creek but were hardest hit in the mid-basin area. At least three factors may be responsible for the higher landslide frequency in mid-basin areas. First, the slopes in the upper portion of the basin may be better adjusted to intense precipitation events. Second, land use has been more intense in mid-basin areas. Third, the inner gorge slopes in the mid-basin areas may have been vulnerable to undercutting by high peak discharges. Unfortunately, we do not have either a long-term or an event record for headwater areas at Zayante Creek basin, but we know that precipitation was very intense in mid-basin areas. Streambank cutting was a major contributing factor to landslides in the SMss, but overall the volume attributable to stream-induced landslides was not great….We conclude that the observed pattern of landsliding was due more to the interaction of intense precipitation, saturated soil and colluvium, hillslope gradient and land use than to the interaction of peak discharge with inner gorge slopes.

3.3.3.c Channel conditions

Sediment is delivered to streams both chronically and episodically. Natural ecosystems have adapted a resiliency to episodic sedimentation. However, chronic human activities increase the magnitude of these episodic events, often to levels beyond the natural system's ability to transport sediment. Human disturbance also causes chronic sedimentation, which creates the most significant impact to natural watershed processes and health. While it is difficult to control episodic sedimentation, erosion control efforts can reduce chronic sedimentation, and such efforts are key in reducing cumulative watershed impacts.

The characteristics and patterns of runoff within a watershed strongly influence the locality and magnitude of sediment deposition. Areas of the San Lorenzo River watershed naturally have episodic storm events with peak rain and streamflow events that rise and drop very fast. This leads to natural peaks of sediment transport followed by rapid deposition. Suburbanization, roads, impermeable surfaces or the denuding of areas within a watershed cause higher peak flows, which briefly increase the streams ability to transport materials.

3.3.3.d Sediment transport

Transport within stream systems is dependent upon particle size, water velocity, turbulence, channel gradient, and channel morphology. As stream velocity increases, so does its ability to transport material. Narrower channels with faster stream velocities have greater ability to transport material. Wider channels with slower stream velocities are likely to be areas of deposition.

According to Butler (1981), natural erosion rates in the watershed at that time fluctuated between 750 to 1,250-tons/square mile/year depending upon variations in geology, soils, steepness of slope, rainfall and drainage patterns, vegetation, and land use. After substantial rains, the soil becomes saturated resulting in high runoff and loss of structural integrity of soils. During these times erosion, especially from mass wasting, and slope failures is most prominent.

During the relatively wet year of 1973, a total of 438,204 tons (331,970 cubic yards) of sediment were carried down the river past the Big Trees gage in Felton. This indicated an average sediment production for that year of 4,134 tons per square mile from the watershed. During the same year the highly erodible and disturbed upper Zayante Creek sub-basin lost 7,884 tons of soil per square mile (County of Santa Cruz, 1979).

Swanson Hydrology & Geomorphology (2001) describes three "thresholds" of sediment transport within a watershed:

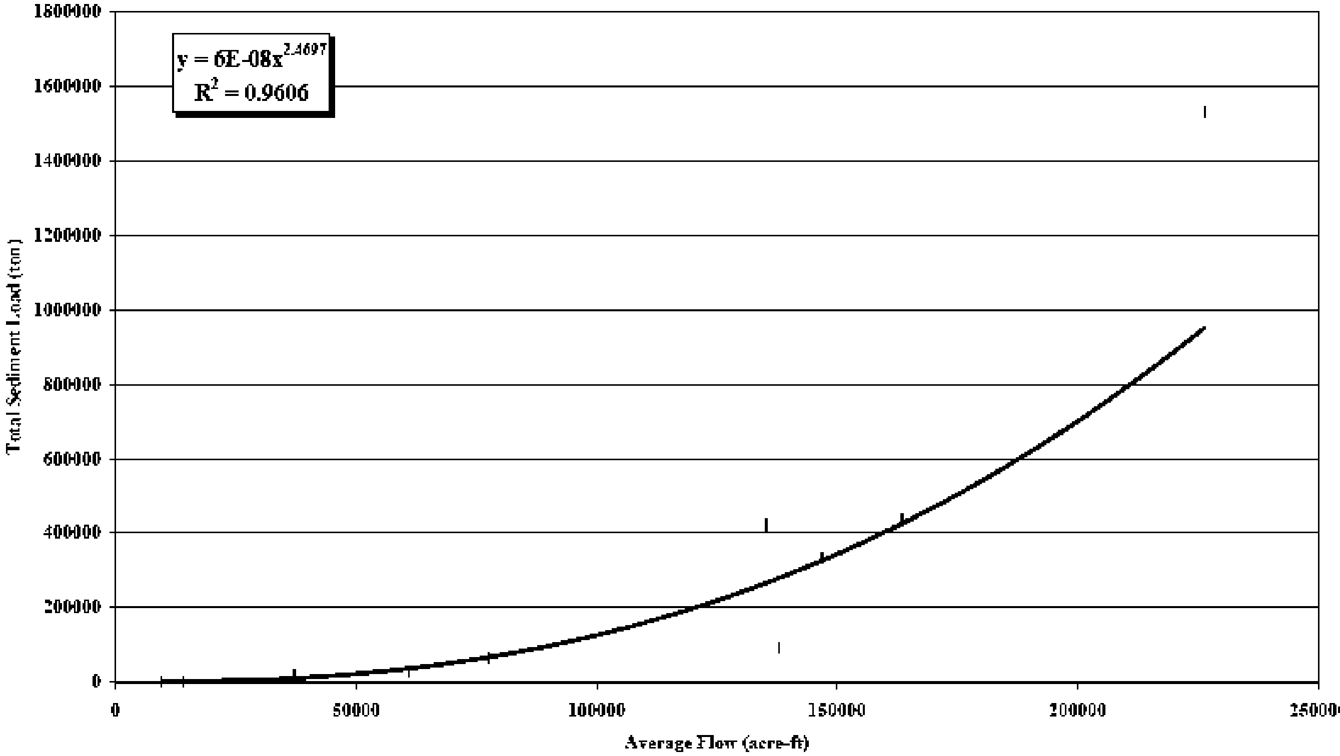
> The first threshold of sediment supply and delivery is due to small and common rainfall events where sediment is mobilized from the surfaces of hillslopes in areas of weak soils and from the bed and banks of high order stream channels. With increasing rainfall, the second threshold is reached and sediments in steep tributary streams are mobilized, thereby increasing sediment delivery to high order streams. The final threshold occurs when intense and/or long duration rainfall over saturates soils and triggers landslides from hillslopes, delivering large volumes of sediment to the streams during flood stage.

While fine sediments can be transported slowly most of the year even at low flows, most of the transport of bed material seems to occur during episodic storm events characteristic of the watershed. Nolan et al. (1984) found that 50% of suspended sediments are transported during discharges that only occur approximately two days a year. Nolan et al. (1984) also calculated that 90% of fine sediment is carried by flows that occur on the average once every 15 years. Hecht & Kittleson (1998) found that much of the transport on the San Lorenzo River occurs at flows of between 500 and 5,000 cubic feet per second (cfs).

Coats et al. (1982) calculated that transport of larger substrate (material larger than 8 mm) is not significant until flows of 500 cfs; flows of this level are reached about 0.51 days a year. It is these larger, winter flows that rearrange habitat and release embedded sediment to be transported downstream. Nolan et al. (1984) stated that the geomorphology of most intermediate and larger channels appear to reflect effects of moderate events as much as catastrophic events; however, the geomorphology of smaller, steeper channels strongly reflect the effects of extreme events.

Swanson Hydrology & Geomorphology plotted annual suspended sediment yield against annual streamflow volume for the San Lorenzo River, using data from the field gage at Big Trees station in Felton. Figure 3.13 shows the rating curve, which was used to extrapolate sediment yields over the stream flow record from 1939-1998, to estimate an average sediment yield. Figure 3.14 shows the synthetic suspended sediment yield for the San Lorenzo River.

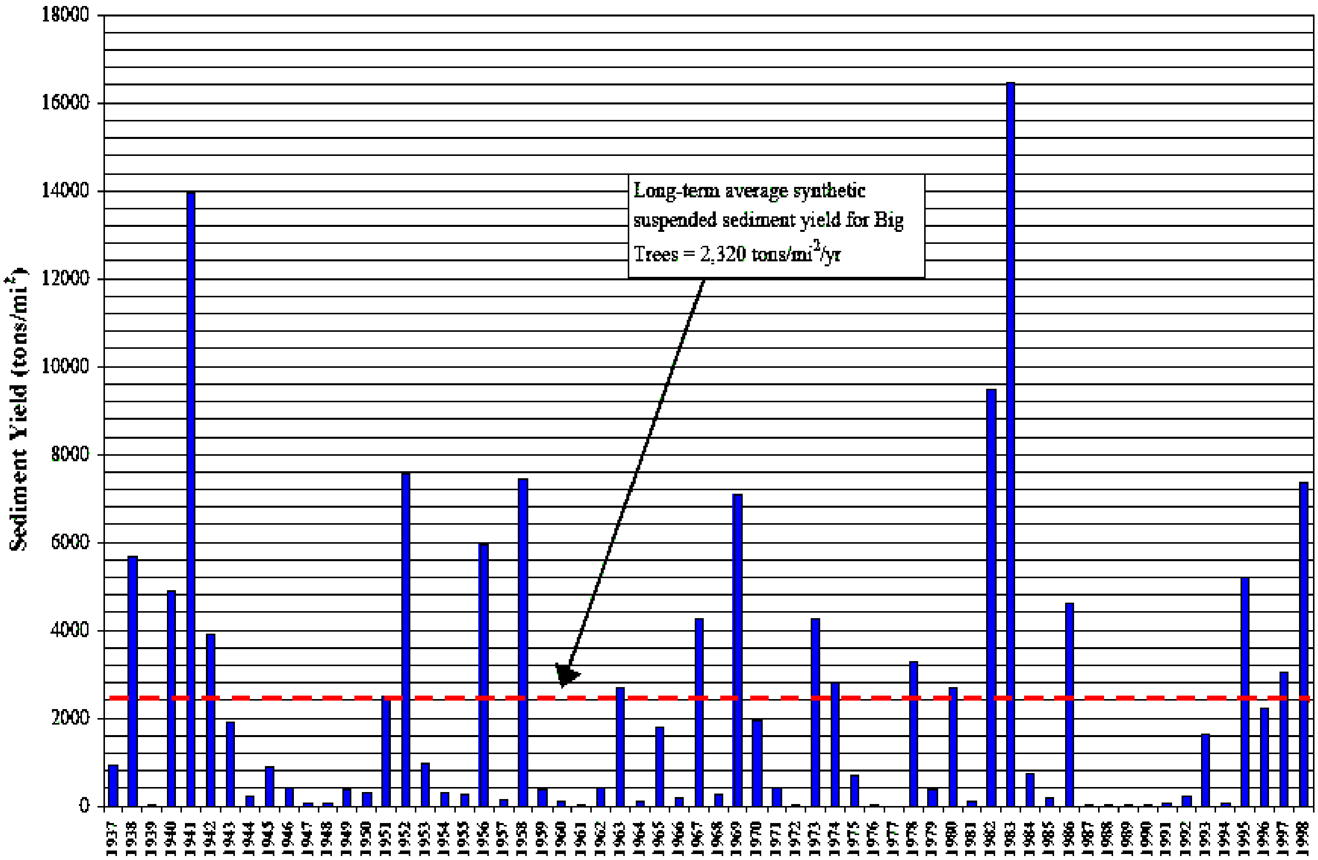
Figure 3.13 Sediment yield rating curve for the San Lorenzo River at Big Trees*



*USGS Station #11160500

Source: Swanson Hydrology and Geomorphology, 2001.

Figure 3.14. Synthetic suspended sediment yield for the San Lorenzo River at Big Trees*



The dashed line represents the long-term average synthetic suspended sediment yield.
*USGS Station 11160500
Source: Swanson Hydrology and Geomorphology, Zayante sediment study, 2001.

Impervious surfaces such as roofs and driveways greatly increase runoff. Landowner responsibilities to reduce runoff and erosion problems are not well defined. Landowners may attempt emergency fixes without regard to downslope conditions. Undersized, plugged, poorly installed, or inadequately maintained culverts lead to drainage problems. Failed culverts exacerbate erosion and sediment transport within the watershed.

3.3.3.e Bed sedimentation

Maintaining adequate streamflow is necessary to maintain adequate sediment transport within the streams of the watershed. When the hydraulic force of a stream is insufficient to move instream material within the water column (suspended load), or roll it along the bottom (bed load), the material is deposited or remains in the stream until the next major storm. A certain level of streamflow is required to keep fine materials suspended; below this level, sand and silt settle out into the streambed, filling pools, riffles, inter-boulder and inter-gravel spaces.

The dynamics of the channel bottom also affect transport and deposition. Objects within the channel break up the flow of the stream, cause turbulence and areas of increased velocity and change flow directions. Turbulent areas can pick up material and bounce it along the bottom. Boulders, logs or rootwads in the stream become scour objects. Water speeds up as it moves around scour objects, scouring material off the bottom near the object. This material can be deposited a few feet downstream or transported long distances.

Excess fine sediments fill the inter-boulder and inter-gravel spaces and change channel dynamics, greatly affecting streamflow dynamics. As the stream becomes embedded with sediment, the channel becomes smoother, turbulence from roughness decreases, transport of material decreases, and so deposition increases. The channel will continue to aggrade (fill with sediment) until streamflow increases or a scour object enters the stream. Aggraded reaches can store large quantities of sediment with residence times of up to thousands of years (Swanson Hydrology & Geomorphology, 2001). The negative impacts of sedimentation on fisheries habitat is discussed in Chapter 4.

Large instream wood, log clusters, check dams, and reservoirs all act as sediment entrapment basins. By creating an area of slower moving, non-turbulent water the stream no longer can suspend the sediment and the material deposits behind the dam until the "theoretical base level" created by the dam is reached (Mount, 1977).

Instream wood increases the storage capacity of the stream, modulates excess sediment transport, and reduces embeddedness elsewhere in the stream. Stable instream wood forms a stair step channel, which dissipates stream velocities and forms dynamic channel morphology for diverse and abundant habitat characteristics.

3.3.3.f Sedimentation trends

According to Hecht & Kittleson (1998), the only areas where existing data allows long-term historical analysis are Zayante and Bean Creeks and the Lower San Lorenzo River. Hecht & Kittleson initiated research and monitoring throughout the watershed, recommending that it be repeated every 3-5 years, and after every large storm event.

State Department of Fish and Game stream surveys conducted in 1966 and 1972 noted that within the bed composition of the main stem of the San Lorenzo River, silt increased from 8 percent to 65 percent; while spawning gravel decreased from 20 percent to 2 percent (County of Santa Cruz, 2001).

Hecht & Kittleson (1998) concluded that stream conditions had not substantially improved between the 1979 County of Santa Cruz Watershed Plan and their 1996 surveys. They found that, "sediment sources and the causes of erosion have remained fundamentally unchanged since the inception of the first watershed plan."

Hecht & Kittleson (1998) surveyed bed sedimentation in the San Lorenzo River watershed, drawing the following conclusions:

- There appears to be a general fining of bed materials at all sites except the San Lorenzo River at the Felton Diversion. While the limited number of samples at each study site may preclude a definitive trend analysis, contemporary conditions do not show improvement in reduction of sediment supply or improvements in gravel availability and/or embeddedness of gravel size material.

- Proportionately less bed material in Zayante and Bean Creeks appears to be generated now north of the Zayante fault. Quartzites and volcanics, which originate almost exclusively north of the fault, are only about half as abundant as in 1978-81. These two rock types are both very durable and are also easily identified, so we believe this finding to be especially informative. Proportionately more sediment is originating from areas downstream of the Zayante fault, most of which are sandy.
- Proportionally, more sediment is generated in middle and lower Bean Creek subwatershed than in earlier evaluations, based on gravel lithologies.
- There is a sharp decrease in relative bed material sizes at the station on Bean Creek below Lockhart Gulch. It appears that Lockhart Gulch is overwhelming the monitoring site with sand. Development-related disturbance and road slipouts in Lockhart Gulch are likely sources. Slides and associated gullies on Bean Creek Road, particularly a set of slides 0.5 miles north of Camp Evers, also are significant sources of fines to this reach.
- In streams where residents have undertaken individual streambank stabilization efforts, concrete rubble, cinder blocks, asphalt, baserock and other road-related materials may make up 15 percent or more of the streambed surface. It appears that the presence of these types of materials originated from previous uncoordinated stream bank protection projects. In sections of lower Branciforte, Carbonera, and Bean Creeks, these materials and sand make up the majority of the bed surface. The addition of these materials may have de-stabilizing geomorphic consequences by forming bars and braids in sandy reaches with less-coherent sandy banks and a disturbed riparian buffer zone.
- There is a marked increase in introduced rock types (roadbed, asphalt, and concrete) in Zayante Creek at Graham Hill Road. This was particularly notable in the gravel size classes. About 11 percent of the bed surface is composed of materials entering the stream from the road surface. Nearly all of these materials are associated with roads and point to the importance of roads as sediment sources.
- Future sampling should include establishment of several study sites on the mainstem San Lorenzo. Besides ongoing fish habitat evaluations done by Don Alley & Associates, the historical data are limited. Priority for future bed sampling should include sites above the Zayante Creek confluence, below the old USGS gage on the San Lorenzo (possibly to Paradise Park), and reaches above and below Boulder Creek, Bear Creek and Kings Creek, and on lower Carbonera and Branciforte Creeks. Boulder Creek and Fall Creek sites would also allow for valuable information on bed conditions in the crystalline-bedrock channels that drain Ben Lomond Mountain.
- Existing fisheries enhancement projects that have been implemented at former geomorphic study sites can and should be monitored to assess these structure's effects on local bed conditions. There exists a unique opportunity to use historic baseline conditions data to evaluate the different habitat enhancement designs that have been put in place in the Zayante Creek watershed.
- Bed monitoring is effective in describing changes and trends in streambed conditions if repeated regularly by informed investigators. The two key issues in this type of hands-on field study of bed conditions is that it is done during low flow periods (thereby making it safer for volunteers), and that it can develop trend analyses which can supplement other

fisheries studies in the system. The sites which can still be used should be re-measured at intervals of 3 to 5 years (avoiding times when the bed is episodically sedimented), and no longer then 5 to 10 years, to evaluate the effectiveness of ongoing efforts to improve habitat conditions and recreational values, as well as to protect the quality of community water supply and the habitats of key, sensitive, and/or listed species.

3.3.3.g Upland sediment sources

In 2004, Alley et al. completed a comprehensive geomorphic survey of the San Lorenzo River and its tributaries. Alley et al. (2004) measured extremely high embeddedness in the Upper River, Kings Creek, Bear Creek, and the Rincon area, consistent with past findings made by Alley. From these surveys, Alley et al. (2004) concluded that sediment loads are coming from upland sources such as Kings and Bear creeks and from the more developed subwatersheds of Bean and Carbonera creeks.

3.3.3.h Bank erosion

Excess streambed sedimentation leads to increased bank erosion.

While some streambank erosion is natural, humans increase its rate by altering or removing riparian habitat, which serves as a buffer for acute storm events and chronic bank erosion. Altering runoff and drainage characteristics of upland areas also decreases streambank stability.

An intact riparian forest helps to minimize bank erosion. Breaks in riparian canopy are often associated with bank instability. Once the disturbance is ceased or remedied riparian vegetation will generally re-establish itself naturally. Efforts to stabilize eroding banks without restoring riparian vegetation often fail (Hecht & Kittleson, 1998).

Butler (1981) described bank erosion in cubic yards per 1000 ft reach of stream, and reported bank erosion from a low of 5 cu yd/1000 feet of streambank to extreme rates of over 70 cu yd/1000 ft of bank. Butler (1981) then determined that with about 150 stream miles, the San Lorenzo averages approximately 15,000-20,000 cubic yards of sediment from streambank erosion each year. According to estimates in the San Lorenzo River TMDL (CCRWQCB, 2002), about 60,143 tons/yr of sediment is contributed from channel and bank erosion, equal to about 14.3% of the total sediment load, as shown in Table 3.5.

Table 3.5 estimates sediment yields of each subwatershed of the San Lorenzo River, as well as sediment source categories. This table was included as part of the San Lorenzo River TMDL (CCRWQCB, 2002). The data was extrapolated from sediment studies in the Soquel Demonstration State Forest, and likely underestimates sediment yields from the San Lorenzo River. A previous study of the San Lorenzo River (County of Santa Cruz, 1979) showed considerably higher sediment yields.

Based on the input data available for the analysis, Swanson Hydrology & Geomorphology (2001) calculated that the estimated average sediment yield contributed by bank erosion in Lower Bean, Upper Bean, and Lockhart Gulch alone is 240 tons/mi/yr. Comparing these numbers to load amounts at the watershed scale suggests that bank erosion contributes a significant proportion of the total sediment load to stream channels (Swanson Hydrology & Geomorphology, 2001).

Table 3.5 Estimated sediment yield in the San Lorenzo River watershed, by subwatershed and source category

SubWSID	Sub-watershed	Area (sq mi)	Upland THP roads (tons/yr)	Streamside on steep slopes THP roads (tons/yr)	Upland public/private roads (tons/yr)	Streamside on steep slopes public/private roads (tons/yr)	THP lands (tons/yr)	Other urban and rural lands (tons/yr)	Mass wasting (tons/yr)	Stream channel/ bank erosion (tons/yr)	Total sediment yield (tons/yr)	% of Total	Sediment yield (tons/sq mi/yr)
30412010	Upper San Lorenzo River	11.52	5915	2683	2260	951	134	5491	32085	4712	54321	12.93	4703
30412011	Kings Creek	12.12	10667	4842	1921	1317	319	4648	17419	5172	46315	11.04	3818
30412020	Boulder Creek	11.47	7708	3496	2003	1176	232	4839	10580	5312	35346	8.43	3082
30412021	Ben Lomond	10.32	4143	1879	3147	1509	106	5005	23499	4964	44252	10.55	4288
30412022	Middle San Lorenzo River	15.87	2284	1036	3291	12942	71	8284	12215	8190	36665	8.74	2310
30412023	**Shingle Mill Creek**	0.71	0	0	275	150	0	391	0	358	1174	0.28	1654
30412030	Bear Creek	16.23	9230	4186	2566	1638	246	7368	12975	6422	44631	10.64	2750
30412031	Newell Creek	9.72	1539	698	590	79	49	1018	1503	935	6411	1.53	660
30412040	Zayante Creek	14.02	6924	3140	3376	1432	207	6393	28110	5254	54836	13.08	3911
30412041	Bean Creek	10.41	1753	795	2804	1499	49	5416	13937	6134	32387	7.72	3111
30412042	**Lompico Creek**	2.77	883	401	896	582	23	1378	7156	1236	12555	2.99	4532
30412050	**Carbonera Creek**	7.08	878	398	2583	295	33	3687	4464	3728	16066	3.83	2269
30412051	Branciforte Creek	9.95	1676	760	2051	1744	39	5223	10668	5088	27269	6.50	2741
30412052	Pasatiempo Creek	0.8	0	0	348	0	0	442	2872	0	872	0.21	1096
30412053	Santa Cruz	4.23	0	0	1302	54	0	2327	31	2638	6352	1.51	1502
Total sediment load for **San Lorenzo River** (tons/yr)		137.23	53610	24314	29415	13720	1508	61910	174749	60143	419369	100.00	3056
% of Total			12.78	5.80	7.01	3.27	0.36	14.76	41.67	14.34	100.00		
Sed. yield (tons/mi^2/yr)			391	177	214	100	11	451	1273	438	3056		

Note: Waterbodies listed as impaired by sediment on the 1998 303 (d) List are shown in bold type.

Source: CCRWQCB, 2002.

3.4 Natural disturbances in the San Lorenzo River watershed

Natural disturbances, including fire, storms, floods, landslides, and earthquakes have occurred throughout time, changing the landscape of the watershed. Stream networks and ecosystems have evolved with natural disturbances. Healthy ecosystems and stream systems have a built-in resilience to the impacts caused by natural disturbances, and may even depend on natural disturbances to maintain a healthy state.

3.4.1 Storms and floods

Extreme storm events that lead to flooding are cyclic, as are the disturbances they create throughout the watershed. The San Lorenzo River watershed is prone to flooding, due to its steep topography, extreme episodic storm events, and relatively high water table during storm events.

Flood stage storms can dramatically increase sediment and gravel input and transport within streams. In healthy stream networks, the periodic input of smaller material is necessary for aquatic ecological function. For example, gravels necessary for anadromous spawning generally result from storm events.

The storm of 1956-1957 damaged natural features and human structures, and increased chronic sediment delivery to streams. After this storm, the US Army Corps of Engineers (Corps) built the “flood control” levee system on the lower San Lorenzo River and Branciforte Creeks within the City of Santa Cruz. These levees drastically disturbed the natural ecosystem function of the final miles of the watershed. The channel, filled with sediment, increased the flood risk to the City. The Corps and the City, in the past few years have raised the walls of the levee to increase its flood control ability.

Among El Niño events, the 1981-82 winter storm was the largest, and produced the most intense rainfall ever recorded in the area. It delivered more than 19 inches of rain to Lompico in a 24 hour period. The watershed received over 100 inches of rain that winter. In the aftermath of this storm were road failures, streambank erosion, and landslides throughout the watershed, including the massive Love Creek slide. Runoff from already saturated hillslopes caused extreme erosion and sediment from landslides, debris slides and slope failures impacted all the waterways.

Pools and riffles in all reaches of Zayante Creek were essentially obliterated following the January 1982 storm, except where riffles were formed of large boulders, as below the USGS gage on Zayante Creek. One large pool cut into bedrock in the Olympia reach remained, but it was largely filled with sand following the storm. Significant scouring occurred in all reaches during March and April, as the sand and gravel deposited during and shortly after the storm began to move out of the stream (Coats et al., 1982).

Following this storm, the State Water Resources Control Board organized a study (Coats et al., 1982) to quantify certain aspects of a sediment budget and monitor changes in substrate and channel morphology in Zayante Creek and the lower San Lorenzo River.

> General effects of the January storm on channel morphology included scour in small first- and second-order channels and fill in larger, higher order channels. . . The mean

> streambed elevation of the San Lorenzo River rose 0.85 m, and the remaining sites ranged from 0.46 m of scour on Bear Creek to 0.06 m of fill on the San Lorenzo River near Boulder Creek . . . The most numerous and severe channel modifications were found along midbasin locations of Zayante and Bean Creeks (Nolan et al., 1984).

In all instances within the Zayante area, sediment transport was an order of magnitude higher at lower flows after the flood than it was before (Coats et al., 1982). The massive input of sediment to the system slowed the "clearing the waters" and the transport of sediment along the stream system for a long period of time to come.

Floods can drastically alter stream channels and, in some cases, upland habitats. Floods facilitate the input and transport of large wood into the channel, which provide beneficial structure and aquatic habitat. Floods move larger bed material through the channel, release and flush out stored sediment, and reconfigure channels. Sediment supply to streams in landscapes subject to landsliding and debris flows often have long periods of relatively low sediment input with brief periods of extremely high input, characterized by waves of sediment moving down the stream during flood flows (Miller and Benda, 2000).

Floods often damage or remove sections of riparian ecosystem, opening up stream corridors, and creating variation in habitat and water temperatures within the stream. The result is often increased variability and diversity in aquatic habitat conditions. In response, the riparian corridor may re-establish itself, through revegetation and re-armoring of the stream bank.

Most landslides occur during flood stage storms. Extreme sediment input from flooding can lead to overburdening of the stream system, especially in impaired streams, which are lacking in natural mechanisms capable of absorbing such increases.

As El Niño winters become more frequent, intense storm events contribute more erosion and sedimentation throughout the watershed.

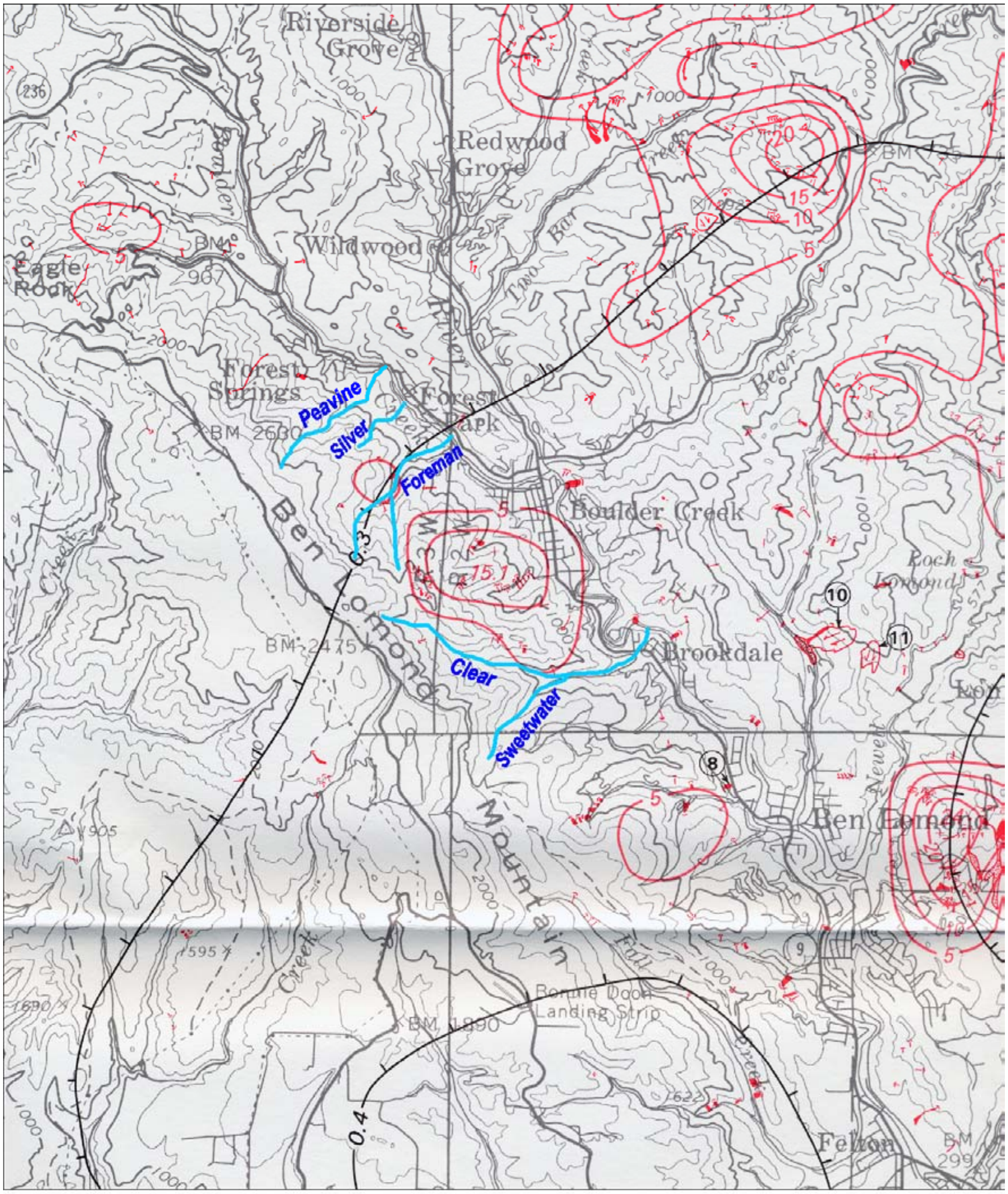
3.4.2 Wind

Wind can erode bare areas and transport sand and other small particles for relatively long distances. Mount (1977) observed that winds blowing across steep quarry faces had transported large amounts of loose sand out of the pit area. In the San Lorenzo River watershed, bare cut faces due to mining within the Santa Margarita Sandstone are especially susceptible to wind erosion. Revegetation efforts are also critical in reducing erosion. Natural unvegetated sand outcrops in the sand hills areas exist in a stable state. For example, Quail Hollow has sand outcrops that are stable due to increased cementation of the sandstone. In addition, liverworts, lichens or other organisms encrust the outside layer, reducing wind and water erosion.

3.4.3 Landslides and mass-wasting

Landslides and mudflows are common in California because of active geologic processes, rock characteristics, earthquakes, and periodic intense storms. Figure 3.15 shows landslides in the area of the District's surface water diversions.

Figure 3.15. Distribution of landslides and debris flows from January 1982 storms.



Red contours represent concentration of debris flows per square kilometer. Black contours represent normalized storm rainfall.

Source: USGS Professional Paper 1434, Ellen and others, 1968, as cited by Johnson, 2002

Landsliding (or mass wasting) is the dominant geomorphic process in the Santa Cruz Mountain landscape. Landslides create a patchy mosaic of geology, soil type and soil stability, which in turn, leads to a patchy mosaic of diverse age and structure of vegetative communities. Landslides can also destroy life and property, increase erosion, sediment transport and sedimentation. For example, a landslide across Conference Drive, destabilized by hydrologic changes to surface and groundwater movement at Kaiser Quarry, is now a major chronic contributor of fine sand to Bean Creek.

In their report on erosion and sedimentation in the Zayante area, Swanson Hydrology & Geomorphology (2001) explained:

> Landsliding results from weak geologic formations, steep topography caused by tectonic uplift, and occurrence of intense periods of rainfall and seismic forces. Landslides often terminate at and impinge upon stream channels, sometimes feeding a seemingly endless supply of sandy material directly into the channels (e.g. Mount Hermon Landslide at Bean Creek). In the worst cases, chronic sediment loading from landslides can eliminate pools, riffles and coarse substrate for hundreds of feet below the point of delivery.

Different types of landslides deliver sediment to streams at different rates. Rapidly moving *debris flow* slides can instantly deliver much of a landslide mass to a stream. Debris flow slides typically begin after intense rainfall elevates soil saturation to a level that liquefies the mass, triggering abrupt and rapid movement (Benda and Dunne, 1997). Debris flows were ubiquitous, and in some cases deadly, within inner gorge slopes in the Santa Cruz Mountains following the January 2-4, 1982 storm.

A *debris slide* is a deeper and more coherent mass that moves along a distinct failure plane; this type can also move rapidly and often with deadly consequences, such as the Love Creek Slide that occurred in 1982. Deeper *slumps* and *rotational* landslides respond to longer periods of rainfall and deep saturation. They move slowly (inches to tens of feet per day) but can deliver significant volumes of sediment when the slump toe is exposed to the stream channel or when large gullies develop in the deformed slide mass. Many large slides terminate at stream banks and feed sediment directly into the stream.

3.4.4 Earthquakes

Earthquakes can significantly change the flows of springs, impact water quality, and cause release of constituents from reservoir-bottom sediments. Earthquakes can also damage underground storage tanks, wastewater treatment facilities, and drinking water treatment and distribution facilities. The 1989 Loma Prieta Earthquake had major impacts on upland erosion and stream function.

3.4.5 Fire

Fire is an important natural disturbance that contributes to a patchy framework of forest age and structure, and increases the overall health and resilience of the forest through time. Forests that are predominately redwood *(Sequoia sempervirens)* are able to resist the effects of all but the most intense wildfires (Agee, 1993). Critical fire weather is concentrated in the months of July through October. Drier inland areas are more prone to fire than moister coastal forests. Forests in areas of high wind are prone to windthrow, which creates a significant fuel load. As the watershed became increasingly developed, fire suppression became an accepted management goal. Fire suppression allowed the build-up of fuel material, increasing the risk of a catastrophic fire. A catastrophic wild fire would create large tracts of bare soil, leading to extensive erosion and sedimentation. Refer to Chapter 5: Fire, which addresses the role of fire and fire suppression, in terms of potential impacts to water quality.

3.5 Human-induced disturbances in the San Lorenzo River watershed

Human disturbance has altered hydrologic processes by increasing the magnitude and frequency of peak discharges and reducing summer base flows (Klein, 1979; Booth, 1991; cited in Spence et al., 1996). Urban and rural development is a major source of erosion and sedimentation. Many current and historic human induced impacts in the San Lorenzo River watershed cause or exacerbate erosion and sedimentation. According to the Draft San Lorenzo River Watershed Management Plan (County of Santa Cruz, 2001):

> Overall, the most persistent, chronic source of sediment to area streams appears to be (1) roadcuts on public and private roads, (2) year-round use of dirt roads, primarily for residential access, and (3) timber harvest road networks. Periodic roadcut failures, grading and leveling of road surfaces continuously expose erodible material both on the road surface and along the road shoulder. This loose, unconsolidated material may be extremely mobile in relatively insignificant rainfall events. Roadcuts along most steep roads are chronic sediment sources. Small cut/fills for residential driveways exacerbate sedimentation problems… Residential land clearing, grading without effective erosion control, and ad-hoc drainage management, active timber harvests and disruption of riparian zones continue to contribute sediment, most noticeably from newer or recurring areas of disturbance.

Hecht & Kittleson (1998) also noted significant human-induced impacts:

> Many erosion sites, mudslides, and landslides result from ad hoc and uncoordinated control for drainage onto, across, and off of private lands and public rights of way. Landowner responsibilities and obligations for management of storm runoff are not well understood and chosen strategies are often emergency “fixes” that neglect to consider downslope conditions. Runoff from roofs, impervious driveways and private roads can greatly increase the volume, velocity and erosive force of offsite runoff. In addition, undersized, plugged, poorly installed, or inadequately maintained culverts and drainage structures can lead to changes in drainage patterns that exacerbate gullying, sheet erosion, or sliding of saturated slopes.

Table 3.6 describes erosion sources identified in a 2001 sediment study of the Zayante area, within the San Lorenzo River watershed (Swanson Hydrology & Geomorphology, 2001).

Table 3.7 lists sediment source estimates in the San Lorenzo River watershed.

Table 3.6 Description of erosion sources in the San Lorenzo River watershed

Sediment source category	Source extent	Erosion description/ types/sources
Timber harvest plan (THP) roads (streamside on steep slopes)	Includes road cuts, shoulders, surfaces, and ditches on permanent and seasonal roads and skid trails	Predominately surface erosion from road-related activities, including erosion from drainage modifications caused by roads. Considered to be 100% human caused, this category was divided into streamside roads on steep slopes (within 200 ft. of a waterway) and upland roads, because of differences in delivery ratios.
THP roads (upland)		
Public and private roads (streamside on steep slopes)	Includes road cuts, shoulders, surfaces, and ditches on paved and dirt roads	Predominately surface erosion from road-related activities, including erosion from drainage modifications caused by roads. This category is assumed to be 100% human caused. This category was further divided into streamside on steep slopes (roads within 200 ft. of a waterway and on slopes less than 15%) and upland roads, because of differences in delivery ratios.
Public and private roads (upland)		
Active and recent THP parcels	Includes all forested land with THPs generated since 1987	Includes all surface erosion including sheet erosion, rills, and gullies. This category has both a human and natural component.
Other urban and rural lands	Includes all forested and unforested lands outside of recent THP plots	Includes surface erosion from sheet erosion, rills, and gullies, as well as mass wasting (i.e.; landslides, debris flows). The mass wasting component was pulled out of the final numbers and put into a separate mass wasting category. This category has both a human and natural component.
Mass wasting	Includes all lands within the study area	Includes erosion from landslides and debris flows, road and disturbance-related mass wasting. This category has both a human and natural component though available data is insufficient to determine proportions.
Channel/bank erosion	Includes all stream corridors within the study area	Includes main channel, banks, and floodplain areas of the stream. Does not include landslide toes or erosion form culvert outfalls. This category has a predominately natural component, though rates can be accelerated from human activities.

Source: Swanson Hydrology & Geomorphology, 2001; Zayante Area Sediment Source Study, as cited in CCRWQCB, 2002.

Table 3.7 Sediment source estimates in the San Lorenzo River watershed

Sediment source category	Erosion rate	Delivery ratio	Sedimentation rate	
Timber harvest plan roads (streamside on steep slopes)	413 tons/mi/yr	1.00	413	tons/mi/yr
Timber harvest plan roads (upland)	413 tons/mi/yr	0.42	173	tons/mi/yr
Public and private roads (streamside on steep slopes)	120 tons/mi/yr	1.00	120	tons/mi/yr
Public and private roads (upland , <=15% slope w/in 200ft. of stream; >15% slope outside 200ft. of stream)	120 tons/mi/yr	0.42	50	tons/mi/yr
Public and private roads (upland, <=15% slope outside 200ft. of stream)	120/tons/mi/yr	0.10	12	tons/mi/yr
Active and recent timber harvest plan parcels	206 tons/mi^2/yr	0.42	87	tons/mi^2/yr
Other urban and rural lands	1,310 tons/mi^2/yr	0.42	550	tons/ mi^2/yr
Mass wasting	3,570 tons/mi/yr	0.42	1500	tons/mi/yr
Channel/bank erosion-alluvium and Santa Margarita Sandstone geologic units	400 tons/mi/yr	1.00	400	tons/mi/yr
Channel/bank erosion – other geologic units	200 tons/mi/yr	1.00	200	tons/mi/yr

Source: Swanson Hydrology & Geomorphology, 2001; cited in CCRWQCB, 2002.

Table 3.8 was derived from Table 3.5 and shows estimates of sediment yields from different sources.

Table 3.8 Sediment source categories and estimated contributions

Sediment Source Category	Estimated Contribution (tons/yr)	Percent of Total
Mass Wasting	174,749	41.7
Timber Harvest Roads	77,924	18.6
Rural/Urban Lands	61,910	14.8
Channel/Bank Erosion	60,143	14.3
Public/Private Roads	43,135	10.3
Timber Harvest Lands	1,508	0.4

Source: CCRWQCB, 2002.

3.5.1 Mass Wasting / Landslides

Due to the watershed's steep slopes, unstable geology and high rainfall, mass wasting occurs at a naturally high rate. The high concentration of human activities and development can reduce the stability of slopes and exacerbate the contribution of sediment from this natural source. Many mass wasting incidents can be linked to human disturbance.

In 1981 Butler described localized, severe erosion problems that are significant and chronic sources of sediment. He estimated that these "major problems" contributed 8-10% of the total annual sediment load to watershed streams. Specific examples were the Mt. Hermon slide, old quarries, and the abandoned Happyland subdivision.

Twenty years later, according to a 2002 CCRWQCB staff report, mass wasting (the downslope transport of rock, soil, or sediment under the influence of gravity) is the largest single source of sediment load to streams, contributing approximately 42% of the total load (Table 3.8). These results indicate a four-fold increase in the contribution of sediment from landslides in the past twenty years, when compared to the Butler report (1981).

The two studies did not use identical methods, and the later study included the massive 1982 Love Creek slide, as well as the Bean Creek slides.

Swanson Hydrology & Geomorphology (2001) estimated that the Love Creek Slide contributes a total of 46 tons/yr of sediment off the slide toe, and the Mt. Hermon Slide contributes a total of 1,030 tons/yr of sand to Bean Creek. When Bean Creek Road sediment delivery is added, a total of 1,470 tons/yr of sand is estimated to be delivered to Bean Creek (Swanson Hydrology & Geomorphology, 2001).

3.5.2 Roads

Roads have been reported as the primary sediment source in the San Lorenzo River watershed (Butler, 1981; Coats et al., 1982; Hecht & Kittleson, 1998; County of Santa Cruz, 2001; Swanson Hydrology & Geomorphology, 2001). A detailed study of 48 northern California watersheds found that the average effect of roads was to increase sediment yields by 37% (Anderson, et al., 1976 as cited in Mount, 1977). Roads also increase the risk of chemical pollutants entering waterways and water supplies.

All forms of roads including abandoned logging roads, dirt roads, private roads, public roads and highways form a network affecting a great portion of the watershed. Roads increase runoff and focus flows, creating a high erosive capacity.

The pervasive road network in the San Lorenzo River watershed is very effective in transporting sediment to streams. According to the CCRWQCB staff report on the San Lorenzo River TMDL (CCRWQCB, 2002), roads contribute approximately 29% of the sediment that enters the streams of the watershed. Of this amount, approximately 19% comes from timber harvest roads and skid trails (the second largest single contributor of sediment to streams), and approximately 10% comes from public and private roads (Table 3.8).

With some detective work to trace the source of these materials, Hecht & Kittleson (1998) discovered:

> The portion of the bed composed of baserock used in road construction and maintenance has increased slightly in the two watersheds where most measurements have been made. Nearly all of the baserock is composed of a distinctive rock type produced only at one quarry (Felton Quarry), which did not become the primary source of such materials until the early 1970s. Hence, it is clear that current roads and practices are largely responsible; first-time failures of older roads constructed more than 30 years ago are not a significant factor because older types of baserock were not encountered.

According to Hecht & Kittleson (1998), “The major sources of bed sediments related to roads are (1) unpaved, or unimproved, road surfaces, (2) continuous use of unsurfaced roads throughout the rainy season, (3) road slipouts and roadcut failures, (4) undersized, poorly maintained or improperly installed culverts and drainage structures, (5) change in use from timber harvest access to residential access, and (6) failure to maintain roads between timber harvests.” Swanson

Hydrology & Geomorphology (2001) reports that erosion from road surfaces, ditches, shoulders and other human-induced land clearing contribute mostly fine-grained sediment.

3.5.2.a Unpaved roads

The most persistent, chronic source of sediment to streams is the year round use of unpaved roads. From their field inventory, Butler (1981) estimated that unimproved roads contributed approximately 35% of the total annual sediment load to the San Lorenzo River, compared to 15% of the total annual sediment load contributed by paved roads. Routine grading and leveling of dirt road surfaces creates loose material along the road and on the shoulder that can be easily transported during rains. Clearing of ditches and berms also creates loose soil. Clearing vegetation from road shoulders exposes soil to erosive forces.

3.5.2.b Continuous use of roads through the rainy season

The continued use of dirt roads through the winter months greatly increases erosion and sediment transport throughout the watershed. With rainfall softening the road surface, ruts form. Puddles that form in these ruts further erode and deepen the ruts. Ruts then become targets for road maintenance, which involves more clearing and grading, perpetuating the disturbance cycle. Winter use without proper maintenance can lead to the compromising and breaching of erosion control structures such as water bars, which, in turn, leads to concentrated runoff. If unchecked, concentrated runoff results in rills, gullies and accelerated erosion damage.

3.5.2.c Road slipouts and roadcut failures

Small, paved mountain roads also cause erosion damage and contribute to sedimentation throughout the watershed. Paved roads increase runoff and concentrate flows, which increase erosive forces downslope. Paved roads generally have exposed cut banks and shoulders, and inboard ditches. As a result, the impermeable paved surface leads to an increased volume of runoff. As it leaves the road surface, it can overwhelm roadside ditches, culverts and natural channels. Any accumulated sediment is mobilized and transported downstream.

Roads can exacerbate geologic instability, landslides, mudflows or debris flows. Often roads cross a preexisting failure with no engineering and improper drainage. When a road fails it may be rebuilt without regard to the geologic instability. Often it is “too expensive” or “too difficult,” or “too ecologically damaging” to reroute the road. This cycle appears more often on timber harvest roads, public roads and highways than on residential roads. Routing new roads around these instabilities, or to span them, should be incorporated early in the design or grading review (Hecht & Kittleson, 1998). Hecht & Kittleson (1998) found that many private and county maintained roads cross old landslides and debris flows or cones.

Roads located along streams in the riparian zone are frequently subject to failure by slippage and/or undercutting as streams migrate into the fill prism below the roadbed (Hecht & Kittleson, 1998; County of Santa Cruz, 2001). Most streams within the watershed have a road running parallel to its course within the steep, “inner gorge” part of the canyon close to bank full water level.

3.5.2.d Undersized or faulty culverts and drains

Culverts can cause severe erosion. Culverts that spill water out without dissipation focus increased surface runoff onto one area. Severe erosion can result. Often these eroded areas lead directly into stream channels. Improperly placed or undersized culverts also lead to erosion problems and are pervasive in the watershed (Hecht & Kittleson, 1998; Swanson Hydrology & Geomorphology, 2001). If a culvert entrance becomes clogged, runoff accumulates and often will spill out on top of fill, causing erosion.

3.5.2.e Change in use from timber harvest to residential and recreational use

Many of the residences or communities of the San Lorenzo Valley share or were developed on old logging roads. Logging roads are generally designed to be simple and cost effective to transport machinery and logs within a property. This design is not optimal for long-term, year round residential use. Residential landowners generally lack the funds or equipment necessary for proper maintenance of logging roads, adding to the problem.

Legacy logging roads and skid trails also attract off-road vehicle and motorcycle enthusiasts. Off-road recreational use of logging lands creates a high degree of disturbance. Off-road recreation of all types has increased in the past 20 years as hiking; mountain biking and horse back riding has gained popularity. Once the area becomes popular for recreational off-road use, enforcement becomes difficult. Putting timber harvest roads and skids "to bed" and effectively gating entrances can help to curtail this abuse.

3.5.2.f Failure to maintain logging roads

For current logging, actively used haul roads and skids usually contribute the majority of a timber harvest site's sediment yield (Hecht & Kittleson, 1998). The CCRWQCB (2002) estimated that approximately 18.6% of the sediment load for the San Lorenzo River comes from timber harvest roads and skid trails. Failed drainage or erosion control measures associated with forest roads or skids may also affect other downslope areas.

Abandoned or legacy logging roads and skid trails continue to act as sources of chronic erosion, long after the last timber harvest operation. Much of the watershed, including private property, public land, and watershed conservation land, has legacy logging roads and skid trails. The amount of compaction, soil removal, and previous erosion often makes natural revegetation slow and difficult. Mount (1977) calculated that abandoned and poorly graded dirt roads contribute more sediment to the river system than all other land uses combined. The decommissioning of legacy roads and skid trails by land owners would greatly diminish the amount of sedimentation in the watershed and improve ecosystem function in the watershed.

3.5.2.g Poor road construction practices

Both paved and unpaved roads in steep areas of the watershed must rely on cuts and fills, which cause geologic instability and erosion. Cuts and fills de-stabilize slopes, alter drainage patterns, promote erosion of roadway surfaces and induce landslides. Roadcuts found along most of the steep roads are notable chronic sediment sources (Hecht & Kittleson, 1998). Much of the watershed is steep and there are often high densities of steep roads. Especially notable are upper watershed roads and communities.

> Roads in steep side drainages, particularly long access roads to homes, retreats, and camps appear to contribute significant sediment to larger tributaries just downstream, particularly when sediment yield is viewed on a road mileage per capita perspective. This is due to the persistent use of unpaved roads in all seasons. Use of baserock on the road surface or

paving the roads reduces rutting, and may decrease fine sediment loads (Hecht & Kittleson, 1998).

Swanson Hydrology & Geomorphology (2001) measured the length of road cuts within the network of roads in the Zayante area to quantify erosion from roads, as shown in Table 3.9. Swanson Hydrology & Geomorphology (2001) found that, "When averaged over the entire area of road cuts, the net surface erosion rate is estimated to be 0.25 inches per year."

Table 3.9. Sediment erosion from road cuts in the Zayante study area

Subwatershed	Sediment Yield from Surveyed Road Cuts using USLE Method (tons yr^{-1})	Total Survey Road Length (mi)	Sample Percent of Total Roads	Per Unit Sediment Yield (tons mi^{-1} yr^{-1})
Lower Bean	457	8.0	26%	57
Upper Bean	111	4.1	26%	27
Ruins	0	0.1	4%	0
MacKenzie	0	1.3	21%	0
Lockhart	224	2.1	17%	106
Love	72	2.9	17%	25
Lower Newell	32	3.8	34%	9
Upper Newell	0	3.0	29%	0
Lower Zayante	384	7.4	25%	52
Upper Zayante	141	6.3	25%	23
Lompico	331	7.9	34%	42
Mountain Charlie	132	3.0	25%	44
W Upper Zayante	302	4.7	30%	64
Summary	**2187**	**54.5**	**26%**	**40.1**

Source: Swanson Hydrology & Geomorphology (2001)

3.5.3 Logging

A majority of the watershed was clear-cut in the late 1800s extending into the mid 1900s. Turn of the century logging removed the stable state old growth redwood forest and created large-scale cumulative watershed impacts. It was common practice to burn the slash to ease the transport of logs out of the cut area. This opened large tracts of the steep watershed to increased runoff, erosion and sedimentation. Historical accounts document higher streamflows due to increased runoff. Logging has continued throughout the watershed at a smaller scale.

3.5.3.a Legacy impacts

In his study of historical logging of North Fork Caspar Creek (a coastal California redwood watershed very similar to the San Lorenzo River watershed), Napolitano (1998) found that the most profound effects of logging persisted from the legacy of 19th century logging. These effects include a relatively simple channel isolated by incision from its former floodplain and the low volume and small size of woody debris. Similar circumstances can be observed in the San Lorenzo River watershed. Zeimer et al. (1991) found that the cumulative impacts of increased sedimentation due to logging may take 100 years or more to allow streams to return to preharvest conditions.

Butler (1981) estimated that logging operations contributed 8-10% of annual sedimentation to the San Lorenzo River. The CCRWQCB (2002) estimated that current timber harvest operations contribute approximately 19% of the total sediment load in watershed streams (Table 3.8), mostly from roads. The actual harvest areas do not have as much soil disturbance, and shrubs and trees naturally revegetate to stabilize the site over time. Even well managed timber harvest areas produce sediment, especially the first winter following construction or harvest (Hecht & Kittleson, 1998).

3.5.3.b Cumulative impacts

According to the Council on Environmental Quality's (CEQ) interpretation of the National Environmental Policy Act, a "cumulative impact" is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency or person undertakes such other actions (CEQ, 1971). The CEQ definition is useful in identifying an approach to land management and impact mitigation, and over time, has been accepted by most researchers and jurists (Reid, 1993).

The magnitude of the impact to a stream channel depends upon the extent and magnitude of the disturbance relative to the size of the contributing watershed. Because these impacts are cumulative, it is difficult to isolate cause-and-effect relationships between disturbance events and channel impacts (Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001). Research conducted over the past 30 years in the Casper Creek watershed in Mendocino County suggests that logging has a considerable impact on channels through increases in peak storm flow, summer baseflows, and suspended and bedload transport rates (Lewis, 1998; Cafferata and Spittler, 1998; Napolitano, 1998 as cited in Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001). Increased peak stormflows result in increased channel down-cutting and channel erosion, which in turn, contribute to increases in suspended sediment loads. Logging can also incur changes in hillslope hydrology from soil disturbance and modifications of drainage pathways. Reduced canopy after logging means that more rainfall hits the soil directly, which results in increased erosion and gullying (Cafferata and Spittler, 1998).

From their modeling of different management regimes affecting erosion and sedimentation Ziemer et al., (1991) found that dispersing timber harvest units did not significantly reduce cumulative effects. Ziemer et al., (1991) hypothesized that current cumulative impact assessments may over-estimate the benefits of dispersion in reducing sedimentation impacts, because effects accumulate over much longer periods than previously considered.

As Reid (1998) concluded, "if enough excess sediment has already been added to a channel system to cause a significant impact, then any further addition of sediment also constitutes a significant cumulative impact." In their modeling of the cumulative effects of logging over hundreds of years, Ziemer et al. (1991) found that the frequency of small changes in stream channel bed elevation dramatically increased, due to logging. Changes in bed elevation due to sediment negatively affect spawning habitat, juvenile fish habitat, invertebrate habitat, productivity and overall water quality.

In discussing cumulative watershed effects, Reid (1998) stated:

> Results of the South Fork Caspar Creek study suggest that 65-percent selective logging, tractor yarding, and associated road management more than doubled the sediment yield from the catchment, while peak flows showed a statistically significant increase only for small storms near the beginning of the storm season.

Pre-Forest Practice Rules methods for roading, yarding and logging were used in the study area of the South Fork Caspar Creek study (Reid, 1998). Sedimentation returned to background levels within 8 years, while minor hydrologic impacts persisted for at least 12 years (Reid, 1998).

The frequency of logging operations increases the vulnerability of the landscape. On a regional scale, areas with an average rotation of 60 years will have 25% of the landscape vulnerable to landslides at any time, versus 15% vulnerability with a 100-year rotation, or 5% vulnerability with a 300-year rotation (Spence et al., 1996).

While there has been considerable improvement in logging practices since the 1970s, current logging practices still result in significant sediment increases to streams. Recent timber harvests conforming to modern state Forest Practice Rules showed an 89% increase in background suspended sediment and bedloads, while logging operations in the 1970s showed a 212% increase (Lewis, 1998 as cited in Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001).

According to a study of streambed conditions and erosion control efforts prepared for Santa Cruz County (Hecht & Kittleson, 1998) locally observed problems from timber harvesting within the watershed included:

- At-grade crossings in residential, open-space or timber harvest areas are chronic sediment sources.
- Harvest landings may eventually be converted to home sites without measures to anticipate and reduce erosion, both at the home site and along access roads.
- Timber harvests can result in road networks, which may result in ongoing erosion as neighboring or subsequent homeowners modify the road net to provide privacy and as they perform ad hoc repairs of post-logging instabilities.
- We suspect that the construction of multi-purpose road nets (for timber harvest and post-harvest uses) may result in road systems that may be longer or denser than might be built for each use alone. If true, there may be opportunities to reduce erosion through improved design or re-bedding of roads at the time when the post-harvest uses commence (Hecht & Kittleson, 1998).

3.5.4 Rural and urban development

Urbanization significantly alters hydrologic processes by increasing the magnitude and frequency of peak discharges and reducing summer base flows (Klein 1979; Booth 1991 both as cited in Spence et al., 1996). Development is also a major source of erosion and sedimentation.

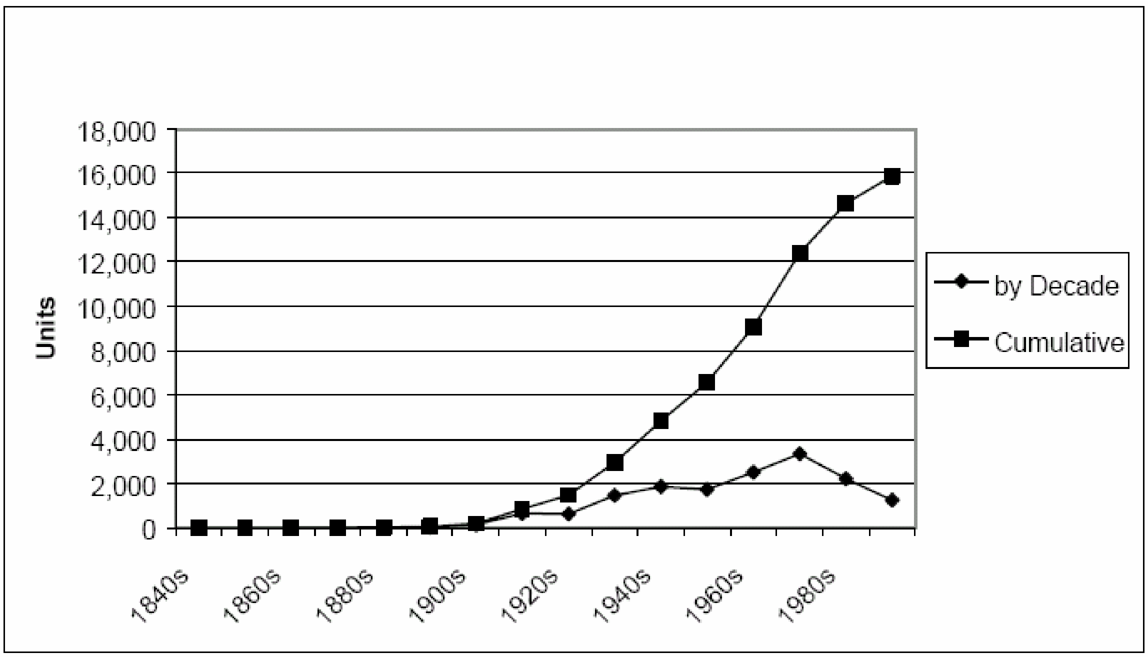
Residential land clearing, grading without effective erosion control, ad-hoc drainage management, and disruption of riparian zones continue to contribute sediment to watershed streams. The CCRWQCB (2002) estimated that human disturbances, related to rural and urban land use, accounts for 14.8% of the total sediment load in watershed streams (Table 3.8).

Prior to 1980, development of new homes and roads was very high, including the conversion of summer homes to permanent residences, as shown in Figure 3.16. Butler (1981) estimated at that time new construction accounted for 25% of sediment reaching the San Lorenzo River and that new construction and associated new road development together accounted for 45-50%. A peak of sediment production occurs during and immediately following new construction, estimated to be 10-100 times that of normal erosion, and after ten years most soil disturbance due to construction or grading activities is minimal or stabilized (Butler 1981).

In the years following this surge, new development continued to a lesser degree but in more remote, steeper locations requiring longer roads traversing less stable, steeper terrain, and in headwater areas. Densities in steeper, less suitable areas increased including erosive sandstones and mudstones. The current level of impact from existing homes and roads adds to the of long-term cumulative watershed impacts. While building new roads increases erosion, improper design and poor maintenance of existing roads has been stated as the primary cause of erosion and sedimentation within the watershed (Coats et al. 1982; Hecht & Kittleson, 1998; County of Santa Cruz 2001; Swanson Hydrology, 2001).

Hecht & Kittleson (1998) reported that higher percentages of existing sites seem to be effectively managed; nonetheless, with more residents there is more activity and contributions from such areas.

Figure 3.16 Development by decade and cumulatively for the San Lorenzo River watershed



Source: CCRWQCB, 2002.

Sandy soil contributes disproportionately high levels of habitat-impairing fine sediments to watershed streams. The Scotts Valley, Quail Hollow, Zayante and Bean Creek watersheds have extensive rural and urban land disturbance. These are key areas of concern for human induced impacts. Information compiled in many studies has shown that erosion in sandy Santa Margarita soils can persist for many years following the initial disturbance:

> Approximately five to ten years after a residential development of about 50 homes was completed in the Lower Newell Creek Watershed, erosion and sediment delivery to streams from roadcuts and the drainage system was still very high (Swanson Hydrology, 2001).

The County of Santa Cruz (2000) and the CCRWQCB (2002) have both expressed the priority of addressing management of impacts within these and other sandy areas of the watershed.

3.5.5 Agriculture

When vineyards are located on steep slopes and have inadequate erosion control measures, they are a source of erosion and increased runoff. At least one commercial and many residential vineyards have been cited by the County Resource Planners as causes of bed sedimentation, impairing fisheries and stream habitat (Camp, Dresser, & McKee, 1996).

3.5.6 Livestock and equestrian uses

Horse and livestock facilities on slopes and encroaching into the riparian zones may locally be notable contributors of sediment. Where riparian vegetation has been lost and use is constant, livestock facilities and stream crossing trails are chronic sources of fine sediment. (Hecht & Kittleson, 1998).

Horses, their facilities and trails can be found throughout the San Lorenzo watershed, including dense concentrations of horses in sandy soil areas. Many residences have one or two horses. Larger commercial facilities can be found in three or four locations. As ground within the corrals becomes denuded, and the soil becomes compacted by horses, runoff and erosion increase. The top layer of soil becomes loosened for transport by wind or water erosion. Corrals are often near or even encompass swales or natural drainages, which can quickly transport soil into creeks, often resulting in sediment deposits.

Equestrian trail use is widespread throughout the watershed. Many trails cross streams or rivers, leading to the direct input of sediment, as well as invasive species, nitrate and pathogens to surface waters.

3.5.7 Mining

Mining has been recognized as a potential contributor to sediment in the watershed since the 1950s (California Department of Water Resources, 1958). Coats et al. (1982) described sand quarry contribution to sedimentation during the 1982 storms.

Sand quarries near Zayante Creek and Bean Creek (in the Santa Margarita Sandstone) provided a major but unquantifiable quantity of sediment in the January 4, 1982 storm. Failure of a sand embankment at a small tributary on Zayante Creek dumped perhaps several hundred cubic meters of sand into the creek, covering the road and destroying a small house in the process. Another quarry on Mackenzie Creek contributed large amounts of sand as a result of surface transport.

Quarries are regulated by the Surface Mining and Reclamation Act (SMARA) and by the Santa Cruz County Mining Ordinance (16.54.030). The purpose of the county ordinance is to:

> Prevent or minimize adverse environmental effects and require that mined lands are reclaimed to a usable condition which is readily adaptable for alternative land uses and implement the policies of the State of California Public Resources Code Section 2710, et seq., commonly known as the Surface Mining and Reclamation Act of 1975, as required by Section 2774(a) thereof.

The county ordinance states:

Significant surface and groundwater resources including springs and aquifers shall not be adversely affected as a result of the proposed mining operation.

The ordinance requires that the application package be submitted to the water purveyor within the drainage area (Camp, Dresser, & McKee, 1996). Each quarry within the watershed has an erosion control and revegetation plan. The County of Santa Cruz and the state inspect quarries to monitor compliance.

3.6 Human-induced disturbances on District watershed lands

The primary human-induced disturbance on District watershed lands is roads, which are used primarily to access and maintain District infrastructure such as wells, water uptakes, the water treatment plant and the five-mile pipeline. In addition, roads are needed for fire and emergency access. Whenever such roads have been cut or trenched, the District uses best management practices to minimize disturbance and erosion. Unpaved roads are out-sloped to facilitate drainage off the road surface. Large rolling dips are used on in-sloped roads for drainage. District staff is trained in erosion control practices. The District routinely maintains its road system each year before the start of the rainy season. Large rolling dips, water bars, or other drainage features are checked and repaired. The use of heavy equipment is minimized to reduce compaction and disturbance. Hand crews maintain drainage and erosion control features as much as possible.

The District has not yet surveyed, mapped, and assessed the existing road system on its watershed land holdings. The District has not yet mapped sites of toxics or hazardous wastes, dangerous cliffs, erosion prone soils, mine shafts, pipeline and overhead power line corridors, etc. that might limit management actions and access

Other erosion problems on District land include landslides and slope failures, which were especially pronounced following the 1982 and 1998 storms. Figure 3.15 shows the location of these debris slides. The District assessed the damage to watershed lands and facilities, and followed FEMA procedures to secure grants and funding to repair damage. The District has codified procedures in its Emergency Response Plan.

Some dumping, especially of old quarrying and mining refuse and equipment, has occurred on District lands, especially at the Olympia watershed property, and on the Fall Creek property.

Staff has observed some recent homeless encampments on both the Fall Creek and the Olympia watershed properties.

Trespass from off-road vehicles and equestrians are an on-going problem on District lands, especially at the Olympia watershed property. An increasingly dense network of trails is being used by both horses and ORVs. For more discussion of this problem, refer to “Chapter 6: Cultural, recreational, and educational resources.”

Invasive exotic species are also an increasing problem on District watershed property. For more discussion of this problem, refer to “Chapter 4: Biotic resources.”

3.7 District water quality

The US Congress passed the Clean Water Act in 1972 to protect and restore the beneficial uses of fresh water bodies throughout the nation. The law is administered by the states; in California, by the state and regional water quality control boards.

The San Lorenzo River has been considered impaired under the Clean Water Act by sediment since 1998, and has since been listed as impaired for nitrates and pathogens. *Impaired* means that the pollutants are significantly affecting the beneficial uses of the waterway, such as drinking water quality, fisheries and recreational uses.

To address these problems, the sediment Total Maximum Daily Load (TMDL) for the San Lorenzo River was adopted by the Central Coast Regional Water Quality Control Board in 2002 and approved by the Office of Administrative Law in 2003. The nitrate TMDL was also approved in 2003. The pathogen TMDL is scheduled for consideration in 2008.

3.7.1 Source water protection and drinking water treatment

As a provider of community drinking water, the District's water quality is regulated under the federal Safe Drinking Water Act (SDWA), which is administered by the state Department of Health Services (DHS) and state Environmental Protection Agency (EPA). The 1996 amendments to the SDWA focused on a new approach to drinking water protection, away from total reliance on water treatment, and toward a more preventive approach. The new laws required every community drinking water provider in the nation to complete a source water assessment (SWA) for both surface water and ground water supplies. Each SWA identifies the source of the supply, either a water uptake or a wellhead, identifies potential sources of contamination to the water source, and assesses the vulnerability of the water source to the contamination source. SWAs were completed in 2002 in California. The new approach to drinking water protection is known as the multiple barrier approach, recognizing that both source water protection and water treatment are necessary for the vast majority of water purveyors. The recent emphasis on protecting watersheds and recharge areas is based on the fact that water that is cleaner to start with is less expensive to treat. Now that SWAs have been completed, the next step in the EPA's Source Water Protection Program is the preparation of Source Water Protection Plans. This step, however, is voluntary.

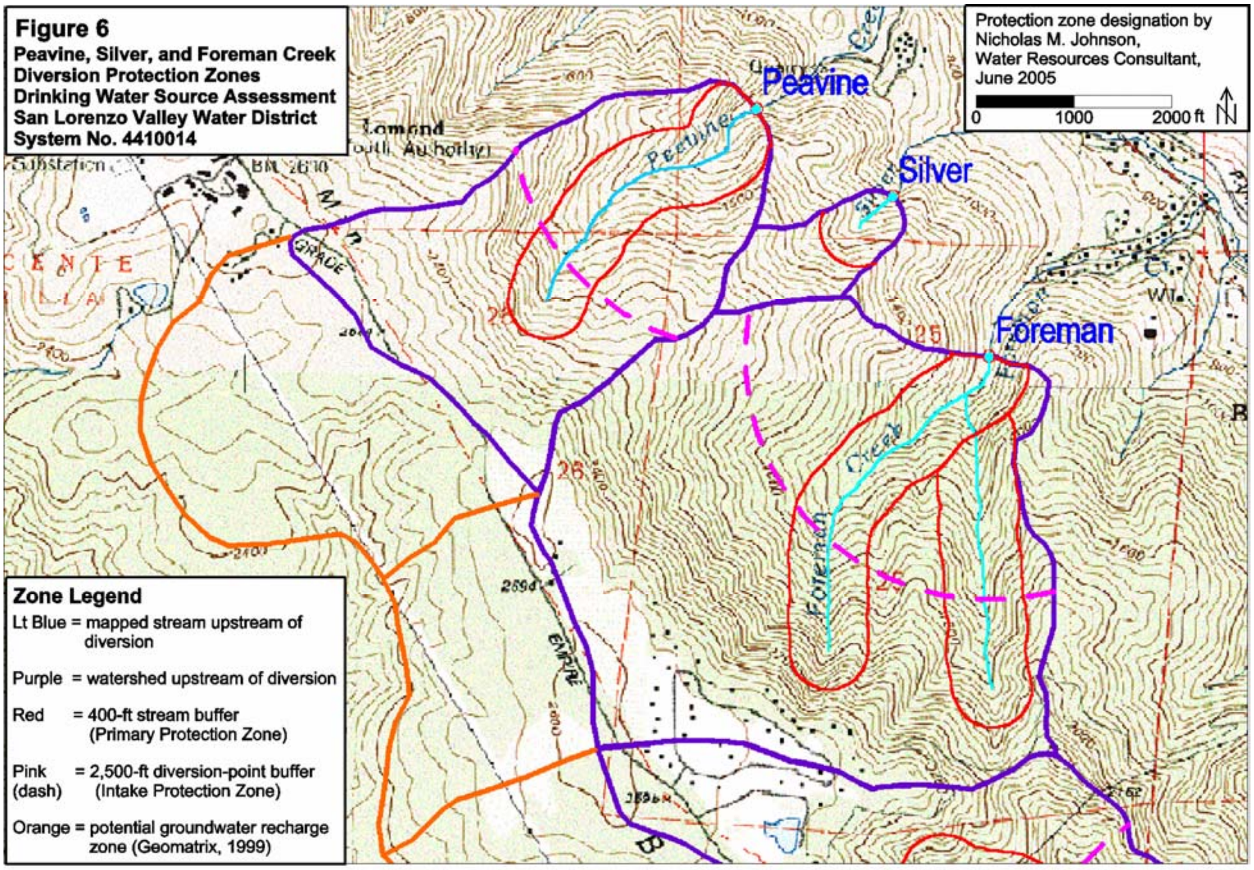
3.7.1.a District source water protection zones

The size of source water protection zones is defined by the DHS. The source water protection zones for District ground water sources are the same as the recharge areas depicted in Figures 3-5 through 3-9.

The source water protection zones for District surface water sources are shown in Figures 3.17 and 3.18. Figure 3.17 shows the stream protection zones and water intake protection zones for the Peavine, Silver, and Foreman creek intakes, as indicated by a District consultant (Johnson, 2005), following DHS guidelines for preparing the DWSAP.

The District does not practice commercial logging on its watershed lands and there are no septic systems located within the source water protection zones shown in Figures 3.17 and 3.18. However, because of the high erosion potential and existence of septic systems in these watersheds, the District’s surface water intakes are considered vulnerable to these land uses (Johnson, 2005).

Figure 3.17. Source water protection zones for Peavine, Silver, and Foreman creek intakes.

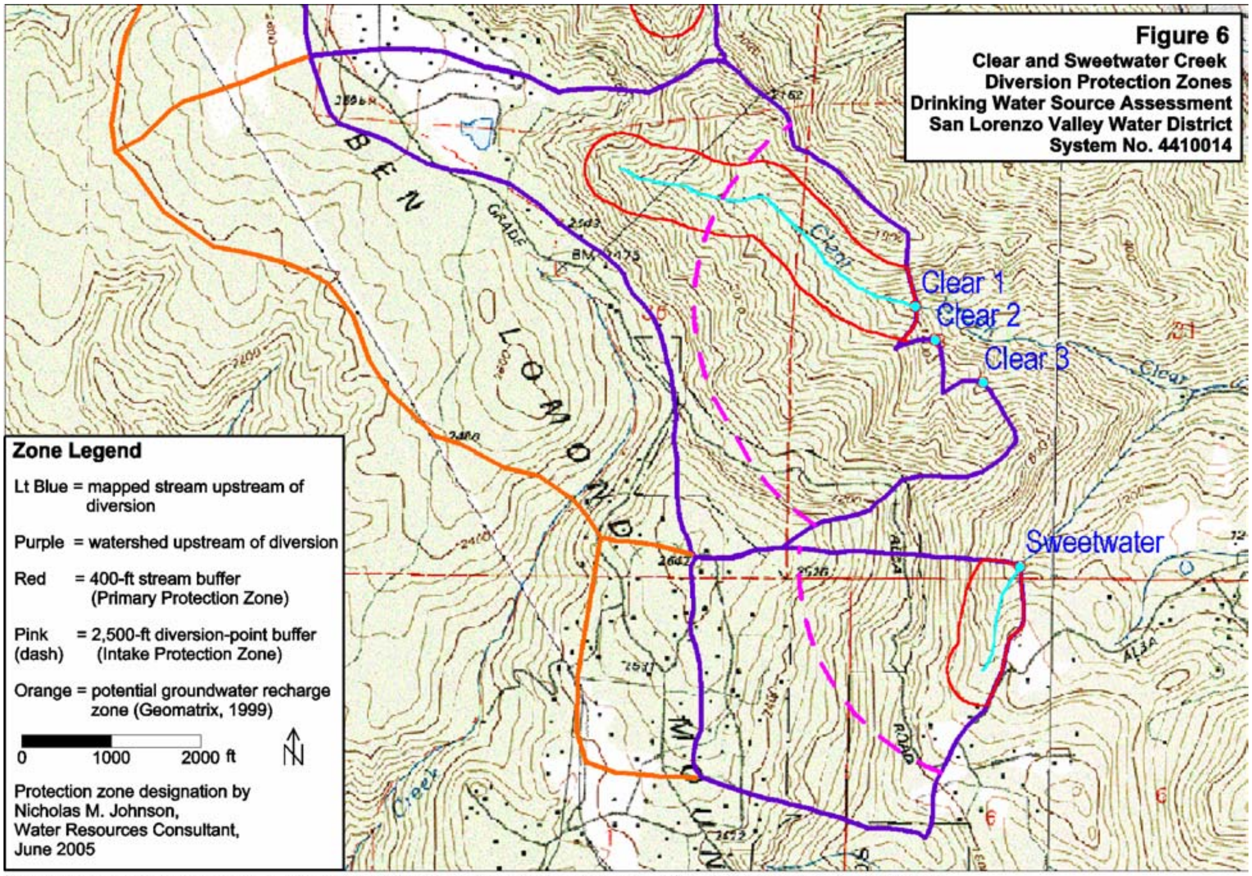


Peavine Ck: Source No. 015, PS Code E44/014-PEAVINE; Foreman (and Silver) Ck:, Source No. 004, PS Code E44/014-RAWFORE

Source: Johnson, 2005

Figure 3.18 shows the stream protection zones and water intake protection zones for the Clear and Sweetwater creek intakes, as delineated by a District consultant (Johnson, 2005), following DHS guidelines for preparing the DWSAP.

Figure 3.18. Source water protection zones for Clear and Sweetwater creek intakes.



Clear Ck: Source No. 003, PS Code E44/014-RAWCLER; Sweetwater Ck: Source No. 021, PS Code E44/014-RAWSWEE

Source: Johnson, 2005

3.7.1.b Maximum contaminant levels

The EPA and the DHS have developed Maximum Contaminant Levels (MCL) for over 100 organic and inorganic compounds. Contaminants in drinking water can be divided into two different categories: those that cause acute illness and those that pose chronic health concerns. Pathogenic microorganisms will cause acute health risks. Excessive concentrations of compounds inherent to source waters, carried into source waters, or created as byproducts of the water treatment process can pose long-term or chronic health risks.

The Total Coliform Rule (TCR) ensures that proper treatment and management of water treatment facilities is in place to ensure microbiological water quality. If water supply sources are found to contain high levels of total coliform, DHS may increase the minimum disinfection requirements for that plant. Other newly adopted regulations include primary MCL for MTBE, Best Available Technology for Fluoride, DHS Unregulated Chemicals Requiring Monitoring, DHS Operator Certification, Federal Interim Enhanced Surface Water Treatment Rule, Federal Arsenic MCL, Federal Disinfection and Disinfection Byproducts Rule, and Minor Revisions Federal Lead/Copper Rule (Berry, 2001).

3.7.2 Surface water quality

The EPA's Surface Water Treatment Rule (SWTR) establishes primary treatment regulations for drinking water supplied from surface water sources. Treatment generally requires both filtration and disinfection. Watershed protection is necessary to meet water quality standards under both the federal Clean Water Act, and the federal Safe Drinking Water Act. Contaminants of primary concern in the watershed include turbidity and sediment, nitrates, pathogens, and toxic compounds.

3.7.2.a Sediment and turbidity

Sediment and turbidity are the primary water treatment concerns for the District's surface water. There are two different categories of sediment sources within a watershed: *point sources* and *non-point sources*. Point sources have a specific location and are easily documented as sediment sources. Non-point sources of sediment have dispersed locations, are less easily documented, though they can contribute significant levels of sediment. Examples of non-point sources of sediment include natural surface erosion and background landslide sources; surface erosion from cleared areas including timber harvest, urban and agricultural areas; erosion from exposed soils along roads including surfaces, ditches, road cuts, shoulders, fill and side cast spoils; surface and landslide erosion stemming from defective road drainage networks; and land use that accelerates channel erosion of banks or streambeds (Swanson Hydrology & Geomorpology, 2001). Section 3.4 provides a more complete discussion of the sources of sediment.

For drinking water purposes, turbidity is often used as a measure of sediment. Turbidity is a measure of the cloudiness of water, and is caused by dissolved or suspended materials such as fine sediment, or residue from organic material, which can act as a carrier for pathogenic organisms, such as Giardia cysts. Turbidity is difficult and expensive to remove from drinking water and can potentially damage water treatment facilities.

Turbidity typically increases dramatically after a storm. In the San Lorenzo River watershed, streams usually clear 1-4 days after a storm. Turbidity is measured in terms of nephelometric turbidity units (NTUs). The Source Water Treatment Rule requires all water purveyors to continuously monitor raw water turbidity as it enters the treatment plant. Water exceeding 20 NTUs is considered untreatable, so most water purveyors in the watershed routinely experience periods during high runoff when they must shut off raw water inputs to their treatment plants. During this time, purveyors must rely on either stored water or other sources.

During a wet year, the District's Lyon treatment plant averages approximately 60 hours of down time due to high turbidity, typically occurring in the period of January – May. This is less than 2% of the average runtime of the plant for the same period, which averages approximately 3,564 hours. During the same period in an average or dry year, the plant averages approximately 40 hours of down time due to turbidity (Busa, 2008).

3.7.2.b Nitrates

Nitrates furnish nutrients that facilitate biological productivity in surface waters. Elevated nitrate levels may adversely affect drinking water and other beneficial uses by stimulating growth of microscopic algae and other organisms, which can impart taste, odor, increase organic load and summer turbidity.

Nitrates also lead to high concentrations of organic carbon. Organic carbon reacts with chemicals used in the disinfection process at water treatment plants. This interaction produces chemical by-products known as such as trihalomethanes (THMs), which pose long-term health threats (Camp, Dresser, & McKee, 1996).

The low flow summer period has the highest potential for biostimulation and other impacts to beneficial uses, so summer nitrate levels are of the highest concern (County of Santa Cruz, 1995). During the summer months, nitrate is also removed naturally from the river system at a rate of about 7% per mile, in both wet and dry years (County of Santa Cruz, 1995). This naturally occurring denitrification process occurs partially within the organic bottom sediments, and partially through uptake by riparian and aquatic vegetation (County of Santa Cruz, 1995). Without this natural denitrification process, nitrate loads in the streams would be expected to be five to ten times greater (County of Santa Cruz, 1995).

Algal influence on nitrates

In other watersheds, nitrogen levels have been observed to directly increase algae levels and to cause detrimental algal blooms. Studies have found that current elevated nitrate levels within the San Lorenzo River system do not seem to be the primary influence of algae growth in streams (County of Santa Cruz, 1995). Results from laboratory studies using *Cladophora spp* collected from the San Lorenzo River have shown no significant effect on algae growth from addition of nitrate and/or phosphate (County of Santa Cruz, 1995).

Algae levels in the San Lorenzo River are apparently at low enough levels in the San Lorenzo River so as not to be detrimental to fish, and may have been beneficial to anadromous fisheries (Gilchrest and Associates, 1984 as cited in County of Santa Cruz, 1995). The County of Santa Cruz (1995) reported that nitrate levels had no noticeable adverse effects on fishery resources, and little impact to recreation.

The County Nitrate Management Plan found that several species of nitrogen fixing algae are common to reaches of the San Lorenzo River; i.e., atmospheric sources of nitrogen are a source of water nitrates, due to these species.

Sources of nitrates

Nitrate enters surface waters primarily by seeping into the streams from septic system leach fields, community sewage disposal systems, runoff from confined animal facilities, and from urban runoff. According to watershed nitrate budgets calculated by the County of Santa Cruz (1995), 84% of the nitrate load in the middle San Lorenzo River is from non-natural sources.

> The daily summer nitrogen load from non-natural sources in the River at Big Trees is comparable to the load that would be generated by 500 houses discharging untreated sewage directly to the River (County of Santa Cruz, 1995).

The County of Santa Cruz (1995) has estimated that septic systems contribute an estimated 57% of the summer nitrate load in the San Lorenzo River. Nitrate levels increased dramatically in the 1970s as a direct result of development and poor septic system management, but increases since the 1990s have been low to insignificant due to management practices, control measures and enforcement (Santa Cruz, 1995 & 2000). Still, nitrate levels are approximately four times greater today than levels in the 1960s. However, the Regional Board updated the nitrate objective when they adopted the TMDL for the San Lorenzo River. Currently, nitrate levels in the River are only about 1.5 times the present objective (Ricker, 2008).

In typical soils of the watershed, approximately 25% of the nitrogen from septic systems is removed by through natural denitrification in the upper soil layers, whereas in sandy soils only about 15% is removed and approximately 75-80% percolates as nitrate to ground water (Ramlit, 1982 as cited in County of Santa Cruz, 1995). In their studies, the County of Santa Cruz (1995) found that 10-25% of the nitrogen from septic systems in the sandy areas underlain by Santa Margarita Sandstone reached the streams as nitrate. The County of Santa Cruz also determined that a septic system in sandy soils contributes 10-15 times more nitrate to the river than a septic system in less permeable soils (County of Santa Cruz, 1995). Approximately 67% of the nitrate load in the river comes from the area of the watershed comprised of the highly permeable Santa Margarita sandstone (County of Santa Cruz, 1995). Therefore, management practices to reduce nitrogen inputs in the watershed will be the most effective in sandy areas.

The County of Santa Cruz and the Regional Board have taken actions to reduce nitrate levels in the watershed (Camp, Dresser, & McKee, 1996). The County of Santa Cruz (1995) found a 20% reduction in nitrate discharge from a shallow trench compared to a deep trench in septic systems in sandy soils. The San Lorenzo River Watershed Sanitary Survey (Berry, 2001) states that nitrate levels in the San Lorenzo River were decreasing slightly from previous levels. Nitrogen control measures and management practices are described in the San Lorenzo Draft Nitrate Management Plan Phase II Final Report (County of Santa Cruz, 1995), the Draft San Lorenzo River Watershed Management Plan Update, (County of Santa Cruz, 2001), in the San Lorenzo Valley and North Coast Watersheds Sanitary Survey (Camp Dresser & McKee, 1996), in the San Lorenzo River Nitrogen Control Measure project (White and Hecht, 1994), addressing the Quail Hollow Ranch Regional Park Stables, and in numerous Santa Cruz County Resource Conservation District (SCCRCD) documents.

The Boulder Creek Country Club sewage treatment facility has been upgraded for denitrification and tertiary treatment for possible use of reclaimed water on the golf course (County of Santa Cruz, 2000). If all other sources of nitrogen are controlled within this area, it is estimated that the San Lorenzo River between Boulder Creek and Ben Lomond could experience nitrate reductions as high as 75% (Berry, 2001).

The County Draft San Lorenzo Nitrate Management Plan (1995) states that livestock and stables contribute 6% of the present summer nitrate levels in the lower River at Felton. In sandy areas, a single horse without nitrate management practices contributes nitrate to streams comparable to rates from a single household in the same area (County of Santa Cruz, 1995). Horses in sandy soils contribute a higher percentage of the nitrogen load due to the highly permeable soils rapidly transporting the untreated waste. There are also high densities of horses in sandy soil areas. For example, horses contribute 41% of the estimated nitrate load in lower Zayante Creek (County of Santa Cruz, 1995). Horses and their contribution to nitrate within the watershed are one of the sources of highest potential reduction due to management practices. The County, the SCCRCD, Camp, Dresser & McKee and Balance Hydrologics have produced documents that contain simple and cost effective recommendations to reduce nitrogen loading from equestrian facilities and trails to ground and surface waters.

Areas where animal wastes are concentrated and left untreated on the surface elevate nitrogen and pathogen levels. This happens through runoff and percolation, especially with the "first flush" of stormwater. According to some studies, horses and horse facilities are one of the principle causes of elevated nitrogen and pathogens within the watershed (Camp, Dresser, & McKee; White & Hecht, 1994; County of Santa Cruz, 2001). Other confined animals such as dogs, cats and chickens also increase nitrate and pathogen pollution.

3.7.2.c Pathogens

Bacteria, virus, giardia, cryptosporidium, and other pathogens can make water unsafe for swimming, as well as require more expensive treatment for drinking water. Most testing for pathogens involves testing for indicator bacteria that would suggest the presence of pathogens from sewage, fecal contamination, or other contamination (County of Santa Cruz, 2001).

While indicator bacteria themselves do not necessarily cause illness, their presence causes warning signs to be posted at beaches, and significantly impacts recreational opportunities.

Sources of pathogens and indicator bacteria are non-point source urban runoff, failing septic systems, sewer system leaks, pet waste, livestock, feral pigs, encampments, and waterfowl. In natural settings, pathogens percolate into the soil where microbial organisms naturally decompose them.

The Watershed Sanitary Survey for the San Lorenzo and North Coast Watersheds (Camp, Dresser & McKee, 1996) found low to moderate levels of coliform bacteria in the tributaries of the San Lorenzo River, such as those that supply surface water to the District. These low levels result from the lack of development and the large areas of intact open space upstream of the water uptakes.

Domestic and commercial wastewaters potentially contain a number of pathogenic microorganisms that can cause diseases such as hepatitis, typhoid, cholera, dysentery, salmonella, giardiasis, and cryptosporidiosis (Camp, Dresser & McKee, 1996). Incompletely treated effluent may reach groundwater supplies or streams from an improperly functioning septic system. However, a properly functioning septic system will remove these pathogens within a short distance by microbial action in the soil.

The Department of Health Services (DHS) requires disinfection to treat pathogenic organisms, at all surface water treatment plants. If water supply sources are found to contain high levels of total coliform, DHS may increase the minimum disinfection requirements for that plant.

Sources of pathogens

The highest levels of indicator bacteria are consistently observed in more dense urban areas such as Scotts Valley and Santa Cruz, indicating that urban runoff and leaks in sewer systems, rather than septic tanks, are the main cause. As the river flows out of suburban areas and through State Parks or other low-density areas, bacteria levels drop substantially as stream flow picks up speed, and natural ecological processes take effect. After passing through the gorge, the river flows through the channelized and heavily developed area of downtown Santa Cruz. Here the river is subject to all the key contributors of pathogens: urban runoff, sewer leaks (within permeable alluvial soils), trash, pet wastes, homeless encampments, water fowl and general non-point human pollution. The river mouth continues to have high bacteria levels and is permanently posted as unsafe for swimming.

Urban runoff can be a source of fecal and total coliform bacteria in stream water. In an urban setting, non-permeable surfaces collect by-products of human activity, pet and animal wastes, and organic debris, holding them at the surface, until they are washed into streams by rain. Moderate to high coliform bacteria levels are frequently measured in the more urban lower San Lorenzo River (Camp, Dresser & McKee, 1996).

A vast majority of residents in the watershed are on private, individual septic systems. An estimated 14,000+ individual onsite septic systems exist in the 138 square miles San Lorenzo River watershed (County of Santa Cruz, 2000). Community sewer systems with treatment serve about 300 homes in the Boulder Creek Country Club, 30 homes in Rolling Woods, 54 homes at Bear Creek Estates, and the Mount Hermon Association (County of Santa Cruz, 2000). The Bear Creek Wastewater System is operated by the San Lorenzo Valley Water District. Both the Boulder Creek and the Rolling Woods wastewater systems are under the jurisdiction of the County Public Works Department (County of Santa Cruz, 2001). The Boulder Creek Country Club facilities have recently been upgraded and improved. All of these community systems including local schools are regulated by the Regional Water Quality Control Board (RWQCB).

The frequency of posting swimming areas in the watershed has also decreased significantly since the 1970s and 1980s due to the upgrading and improved maintenance of septic systems within the watershed. With improved management and monitoring summer bacteria levels have substantially improved, and the river generally meets all standards for safe swimming at all areas upstream of Santa Cruz (County of Santa Cruz, 2001).

The San Lorenzo and North Coast Watershed Sanitary Survey (Camp, Dresser & McKee, 1996) summarized the effects that the large numbers of septic systems have on coliform levels within the watershed:

> The absence of fecal coliforms in shallow groundwater underlying developed areas indicates that incidents of bacterial contamination of surface waters do not result from cumulative contamination of groundwater, but result from failures and discharges to the ground surface from individual systems. Rapid detection of failing septic systems under the Wastewater Management Program has anecdotally reduced the frequency of high microbial concentrations in the San Lorenzo River. The County found that human waste is not the primary source of fecal coliform in the San Lorenzo River based on fecal coliform to fecal streptococcus ratios. After many years of study, the County and Regional Board have concluded that the majority of existing septic systems do not consistently contribute significantly to the bacteria concentrations measured in the surface waters.

An evaluation of the County fecal coliform bacteria data, conducted by the County Health Services Agency, found no significant increase in bacteria in the swimming areas of the San Lorenzo River system.

Greywater systems are common throughout the San Lorenzo Valley and are often utilized to alleviate stress to septic systems with inadequate leaching capacity. Greywater systems collect and dispose of wastewaters originating from washing machines, showers and sinks. Although greywater contains fewer pathogens, solids and nutrients than toilet wastes it can still be a hazard to health and water quality.

According to the Santa Cruz County Environmental Health Services, bacterial concentrations in greywater from shower or bath water can reach 400,000 fecal coliforms and 3 million total coliforms/100 milliliter (ml). Washing machine wastewater can range from 2,000 to 10 million fecal coliforms/100ml. In addition, there are roughly 200 enteric virus/liter of undisinfected greywater from showers and baths and 3,000 viruses/liter from washing machines. County policy requires connection of all greywater to an adequately sized septic system but probably allows installation of at least 25 to 50 greywater sumps each year under appropriate conditions (Camp, Dresser & McKee, 1996).

A marked decrease in septic system failures has occurred since the time when the San Lorenzo Valley was being converted from summer homes to permanent residences. The Santa Cruz County Health Services Agency reported that, "Since 1986, the wintertime septic failure rate has declined from 5-14% to 1-3% depending on the area" (County of Santa Cruz, 2001).

Another source of pathogens is from equestrian trails, paddock areas, and manure stockpiles, which can contribute elevated levels of fecal coliform, Cryptosporidium, and other organisms (County, 2001). Other sources of pathogens are pets, livestock, waterfowl, decaying garbage, homeless encampments, sewage leaks, and general nonpoint urban pollution (County of Santa Cruz, 2000 & 2001). The potential for erosion from horseback riding and the introduction of fecal matter from horses may be significant, especially at stream crossings. However, the effect of horseback riding cannot be quantified separately from other sources which contribute microbial contaminants and turbidity/sediment (Camp, Dresser & McKee, 1996).

Homeless encampments near creeks may dispose of human waste directly into the streams. Even if latrines are dug, the encampments are often within the floodplain. Encampments effect riparian vegetation and concentrate trash. Homeless encampments directly elevate levels of sediment, pathogens, nitrate and particulate contaminants in streams.

3.7.2.d Toxic compounds

Toxic compounds include synthetic organic chemicals (SOCs); volatile organic compounds (VOCs), which include fuel, oil, gasoline, and MTBE; heavy metals, including lead, zinc and cadmium, pesticides, PCBs, oil and grease. The presence of toxic compounds in the San Lorenzo River has primarily resulted from discharge of VOCs from leaking underground storage tanks.

Drinking water aquifers in Scotts Valley and some other localized parts of the watershed have been contaminated by these toxic compounds, which has required discontinuance of wells and/or expensive treatment (County of Santa Cruz, 2001).

Past studies in the San Lorenzo River watershed have indicated low to nondetectable levels of heavy metals, pesticides, PCB's, oil and grease in the San Lorenzo River. There have been no documented impacts on organisms or beneficial uses of the River resulting from toxic constituents in urban runoff. Very low levels of only a small number of trace organic compounds (pesticides and PCB's) were found, at only 2-7% of the level considered hazardous (County of Santa Cruz, 2001).

Elevated levels of lead, zinc, and cadmium have been found, but none of the compounds were found at levels that are known to cause a threat to human or biotic health. Zinc and cadmium are of geologic origin, while lead is a likely result of historic accumulations from vehicle emissions (County of Santa Cruz, 2001).

The EPA has established maximum contaminant levels for volatile organic compounds (VOCs), which include fuel, oil, gasoline, and MTBE, and for inorganic compounds, pesticides, and herbicides.

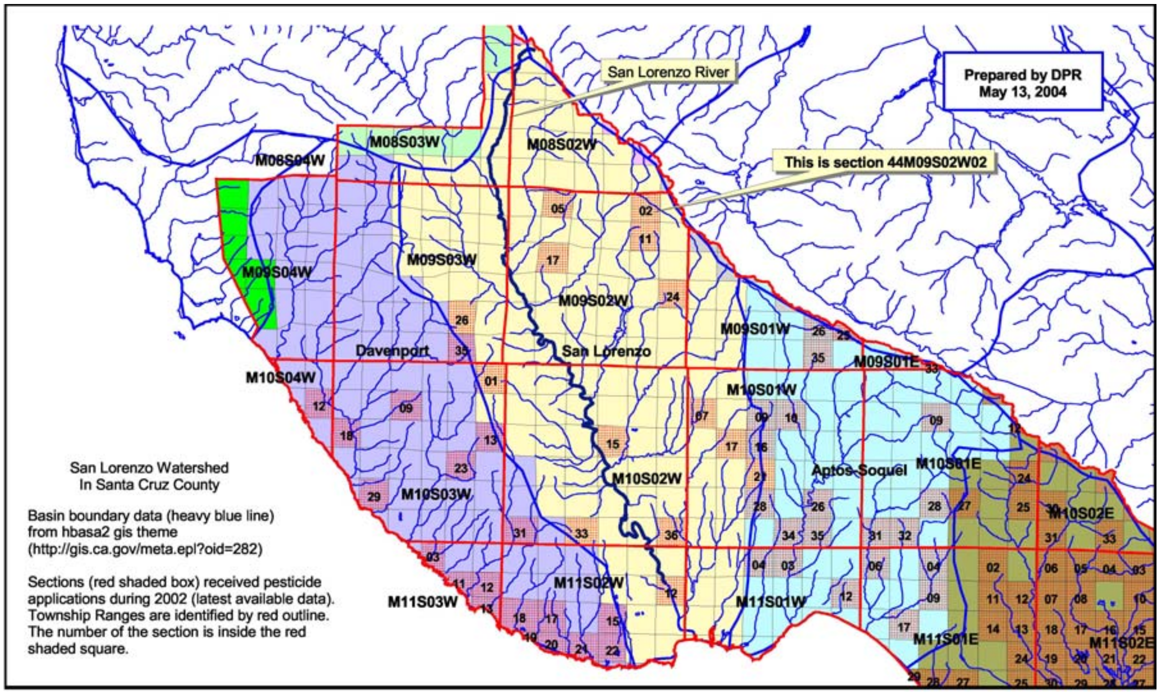
The government agencies that regulate pesticide and herbicide use are the County Agricultural Commission, the California Department of Pesticide Regulation (DPR), and the United States Environmental Protection Agency (EPA).

The San Lorenzo and North Coast Watersheds Sanitary Survey (Camp, Dresser & McKee, 1996) defines pesticides and herbicides and lists their uses as:

> Chemical compounds specifically formulated for their lethal effects on animal and plant life; used in (1) agriculture, (2) rights-of-way along roadsides, (3) landscaped areas such as parks and golf courses, (4) for structural pest control, and (5) by individuals.

All pesticides are considered as undesirable in a drinking water source. The majority of the agricultural and structural pest control applications are in areas of the county outside of the San Lorenzo watershed, as shown in Figure 3.19. The other two reported uses, rights-of-way along roadsides (CalTrans), and within parks, are reported to be used sparingly and are not a significant contaminant source of concern within the watershed (Camp, Dresser & McKee, 1996). Private use of herbicides and pesticides is not reported. Due to public opposition and sensitivity to chemical use, private pesticide and herbicide use is probably low in the San Lorenzo Valley and therefore not a significant contaminant of concern (Camp, Dresser & McKee, 1996). Vineyards are potential sources of organic chemicals from fertilizers, pesticides and herbicides.

Figure 3.19. Areas with reported annual agricultural pesticide and herbicide use in Santa Cruz County, 2002.



Source: California Department of Pesticide Regulation, 2004.

The San Lorenzo River watershed has few industrial facilities that handle or produce toxic compounds. Most are found in Scotts Valley or Santa Cruz. Any facility that handles, stores, or generates hazardous materials is subject to regulation by the Santa Cruz County Environmental Health Services Hazardous Materials program, as well as the state Department of Health Services, the state Environmental Protection Agency, and the U.S. Environmental Protection Agency. According to the County of Santa Cruz (2001), every facility must have a hazardous material management plan to prevent any release of materials into the environment. They are inspected annually, at a minimum, for compliance.

Incidents of contamination of surface waters within the watershed by toxic compounds have occurred. A Chevron station in Felton had an underground storage tank that leaked toxic compounds into the San Lorenzo River. Initial remediation efforts were not completely successful, but additional remediation measures followed (Camp, Dresser & McKee, 1996). Contamination by gasoline also occurred in Boulder Creek (County of Santa Cruz, 2001).

PG&E power line transformers have been found in creeks of Santa Cruz County, though not within the San Lorenzo River watershed. These transformers contain toxic compounds that could potentially be released into stream habitat. PG&E was quick to respond to at least one of the reported transformers found in Soquel Creek.

Abandoned cars are found throughout the watershed including a significant number in watercourses. Traffic accidents are potential sources of hazardous materials from spilled cargo or from petrol-chemicals leaking from the vehicle. A system exists for clean up and the reporting of traffic accidents and other surface spills to appropriate agencies and water purveyors (Camp, Dresser & McKee, 1996).

3.7.3 Groundwater quality

Groundwater quality is subject to impacts from both natural and human causes in the District's water supply area.

3.7.3.a Natural impacts to groundwater quality

Groundwater can be found in the interspaces of geologic materials such as highly porous sandstone, upper weathered portions of granitic formations, or along cracks and fissures found in shale. Waters originating in the older sedimentary formations north of the Zayante fault contain relatively high concentrations of dissolved solids.

Table 3.10 describes the types of rock composing the District's source aquifers in terms of their naturally occurring water quality limitations.

Waters of the younger sedimentary formations, generally south of the Zayante and east of the Ben Lomond faults, contain water of intermediate quality. This area contains Santa Margarita Sandstone and includes Quail Hollow, Zayante, Mt. Hermon and Scotts Valley. Wells in areas of this highly permeable aquifer have lowered and altered the direction of groundwater flow, diminished streamflow, and caused degradation of water quality (Camp, Dresser & McKee, 1996). Some of the ground water recharge in this area is from leach fields or other sources in contact with wastes, resulting in elevated nitrate levels in this aquifer.

Groundwater produced from the Olympia wells intermittently exceeds recommended drinking water standards for total dissolved solids, sulfate, iron, and manganese. This is caused by naturally occurring poor quality water that is believed to migrate upwards from the underlying Monterey Formation (Johnson, 2002).

Waters from the crystalline rocks west of the Ben Lomond fault have relatively low concentrations of dissolved solids and streams of this area tend to provide high quality water at reasonably constant rates.

Table 3.10 Aquifer rock types and their naturally occurring water quality limitations

Aquifer Rock Type	Naturally Occurring Water Quality Limitations
Granite	Relatively low concentrations of dissolved solids. Low recharge. Potential for rapid contamination through fissure flow.
Vaqueros Sandstone	Regionally high sodium, iron, sulfide and fluoride.
Lompico Sandstone	Susceptible to pollution because of high permeability. Variable water quality due to lack of freshwater flushing in some areas.
Santa Margarita Sandstone	Due to high permeability, susceptible to pollution from contaminated recharge water and adjacent aquifers generating poor quality water. Potential source of high phosphate surface waters.
Monterey Formation	High iron and sulfate. Possibly high cadmium and contamination through fissure flow.
Alluvium and Terrace	Water quality varies greatly with composition and quality of recharge water. Often susceptible to pollution because of high permeability.

Source: Haynes, 1985.

3.7.3.b Human impacts to ground water quality

The County Nitrate Management Plan (1995) reports that, "Invariably the nitrate concentrations in surface water are one-half to one order of magnitude lower than the nitrate levels in nearby contributing shallow and deep groundwater." Well pumping directly affects nitrate levels in the surrounding ground water. Johnson (1988) found that as pumping increased, increasing the cone of depression around the well, nitrate was drawn from a wider area and caused nitrate concentrations to increase (County of Santa Cruz, 1995).

In 1986, nitrate levels in the Quail Hollow aquifer rose dramatically and rapidly towards the maximum drinking water standard. At that time, the District used the Quail Hollow aquifer for approximately 25% of its water supply. It was determined that the rapid spike in nitrate levels was due to heavy rains flushing nitrate, stored in the unsaturated zone, from the overlying development. Nitrate levels have since dropped to and remained at low levels, and have not hindered the District's ability to supply clean water.

The recharge area for the District's Olympia well fields is rural and undeveloped, and much of the aquifer lies beneath less permeable mudstone. Where the aquifer is exposed to surface, it has a high percolation capacity, increasing its vulnerability to human impacts.

Several factors contribute to the vulnerability of the Quail Hollow wells. The first is high percolation capacity of the Santa Margarita Sandstone and associated Zayante soils. The second is the absence of a confining zone above the aquifer. The third is the existence of about 40 residential septic tank systems in the estimated wellfield capture zone. The fourth is three unused production wells with the capture zone. Because of high permeability of the soils and sandstone, percolation from quarry detention ponds and the Quail Hollow Ranch pond originates from undeveloped watershed areas, and thus does not pose a significant threat to groundwater quality (Johnson, 2002).

Scotts Valley groundwater is unusually high in nitrate, which is probably from the result of past sewage treatment in Scotts Valley, which involved disposal within the Bean Creek watershed. The Hansen Quarry site is thought to be a primary contributor of the nitrates. For the last decade Scotts Valley has been exporting treated sewage in a pipeline to the Santa Cruz City outfall into the ocean. This makes management and reduction difficult. This "nitrate plume" migrates through the groundwater and contributes about one half of Bean Creek's nitrate load (County of Santa Cruz, 1995). The Scotts Valley nitrate plume has contributed up to 9 percent of the nitrate load in the San Lorenzo River (Camp, Dresser & McKee, 1996)

Septic tanks and horses

The protection zone around the wells contains no development, but the overall capture zones for the wells contain many residences with septic tanks. These residences along with horse stables, riding trails, and active quarrying near the fringe of the protective buffer zone are potential contaminating sources to the aquifer. However, there is no evidence of any water quality influence from septic tanks or horses.

Quarries

An old quarry immediately west of the Olympia wells serves as a stormwater retention basin that recharges the aquifer, and receives stormwater from a relatively pristine, undeveloped area. Potential fuel spills could be associated with active quarrying.

Toxic compounds

When in ground water, toxic chemicals can be difficult to impossible to remove, and may require expensive and elaborate clean up operations.

Gasoline and toxic chemicals leaking from underground storage tanks and illegal dumping of wastes has contaminated ground water aquifers in Scotts Valley used for drinking water. As a result, drinking water wells have been discontinued or have required extensive and expensive treatment. Methyl Tertiary-Butyl Ether (MTBE) was detected in wells in the Manaña Woods and in the Camp Evers area of Scotts Valley. This area is underlain by Santa Margarita Sandstone and may hydrologically connect to Carbonera, Bean and/or Zayante Creeks. The Santa Cruz Water Department has not detected MTBE above limits in any monitoring of its source waters (Berry, 2001).

Past operations at the old Watkins-Johnson Facility in Scotts Valley near Bean Creek contaminated ground water with methylene chloride, chloroform, and trichloroethylene (TCE) (Camp, Dresser & McKee, 1996). These contaminants also reached Bean Creek through the ground water. The EPA has overseen a very extensive remediation project since 1990 (County of Santa Cruz, 2001). Water is extracted, treated and then (considered contaminant free) is used, recharged or pumped into Bean Creek (Camp, Dresser & McKee, 1996; County of Santa Cruz, 2001).

The septic tank of Valeteria Dry Cleaners input tetrachlorethylene (PCE) into the San Lorenzo River via a spring (Camp, Dresser & McKee, 1996). The old septic tank was removed; a new one installed in a new area and clean up efforts ensued (Camp, Dresser & McKee, 1996). The City of Santa Cruz Water Department has not detected any contamination from this site above the detection limit in its water testing (Berry, 2001).

The closed landfill and Ben Lomond Transfer Station appear to have a low level plume with a few volatile organic compounds in the ground water; however, the plume does not appear to be migrating into the creek (Camp, Dresser & McKee, 1996).

3.7.4 The connection between surface water, ground water, and water quality

Surface water quality in the San Lorenzo River and its tributaries fluctuates with rainfall and streamflow. During the wet season, groundwater and surface runoff are high. Wastewater from septic systems and urban runoff transports turbidity, domestic animal waste, nitrates, pathogens and toxic compounds into streams. The County of Santa Cruz (1995) found that with higher levels of rainfall, soil moisture and/or elevated groundwater, there is a greater potential for flushing and delivery of nitrate to surface waters. During dry periods, the stream system of the watershed is fed by ground water. When groundwater enters a stream, it may carry dissolved constituents from geologic formations, discharges from septic systems, and/or other constituents that have percolated into the groundwater from other land use influences.

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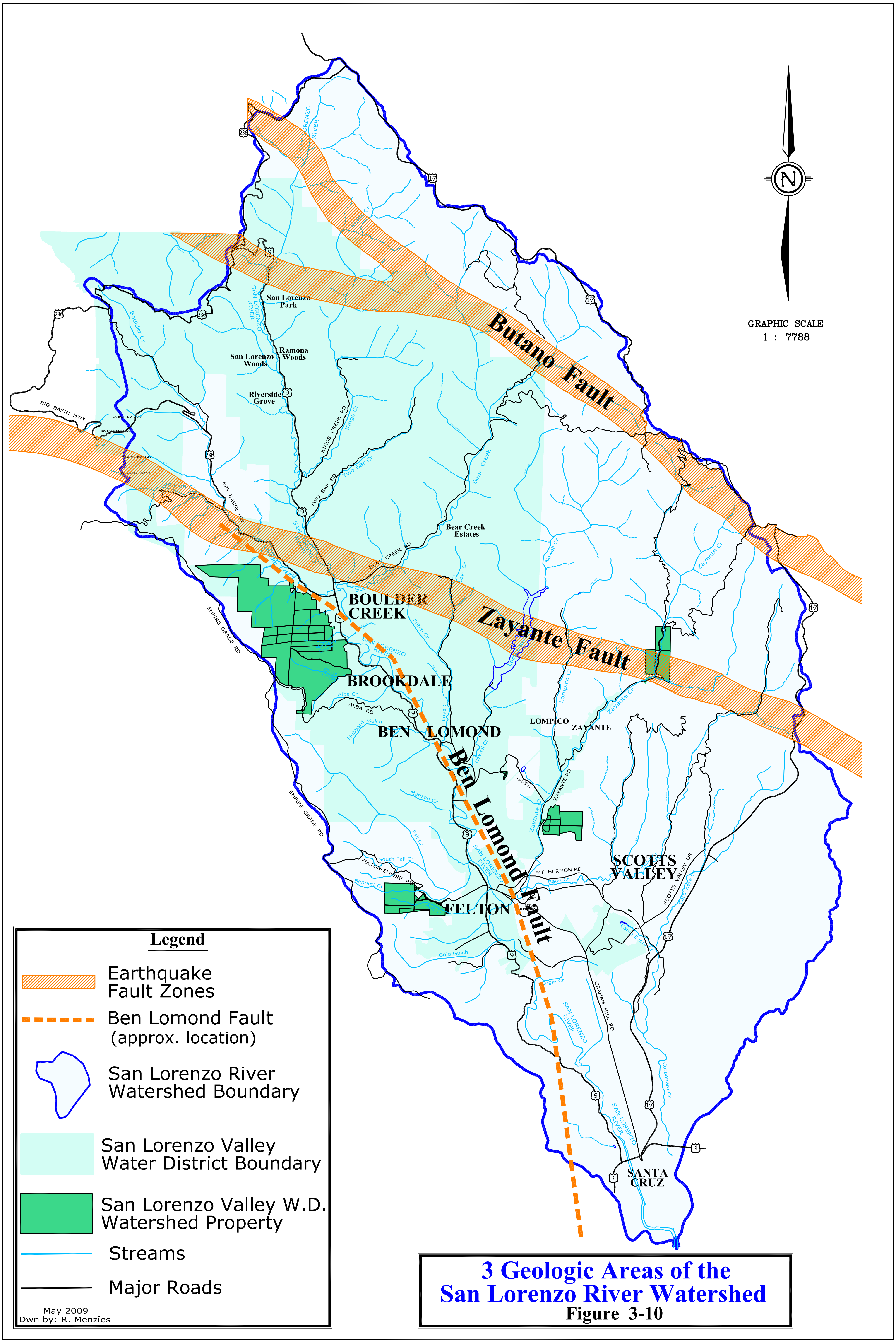


3 Geologic Areas of the San Lorenzo River Watershed

Figure 3-10

CHAPTER 4: BIOTIC RESOURCES

4.0 Introduction

This chapter provides an overview of the biotic resources of the region, the San Lorenzo River watershed, and to the degree possible, on District-owned lands. Because most District-owned lands have not yet been biologically surveyed, the description at this level relies on personal observations of District staff and consultants--as well as the findings of other local studies--to identify communities of plants and animals, to estimate habitat conditions, and to assess future needs for biological surveys.

The District has not yet established measurable baselines of biotic resource quantities, conditions, and locations.

This chapter begins with a brief discussion of biodiversity, and then identifies major plant communities, wildlife habitats, and fisheries. Next, it describes some of the ecosystem functions and natural services provided by these local biotic resources. Finally, the chapter discusses the role of human activities and their impacts to plant communities, wildlife and fisheries habitats, and ecosystem functions.

It should be noted that climate change has the potential to significantly alter fundamental natural processes that biotic resources depend on, such as the carbon cycle and the hydrologic cycle. Thus, the impacts of climate change on biotic resources are likely to be significant at all landscape scales, though the scope and severity of the impacts are as yet not fully known.

4.1 Biodiversity at regional and watershed scales

As discussed in Chapter 2, the Santa Cruz Mountains is defined as a bioregion (Santa Cruz Mountains Biodiversity Council, 2007), which is home to plant communities, such as those of the sandhills, which are found nowhere else in the world. Santa Cruz County, which lies within the Santa Cruz Mountains, is considered an international “hot spot” for biological diversity because of its unique habitats and ecosystems (Dobson, et al. 1997; McGraw, 2004).

The biological diversity of the Santa Cruz Mountains also characterizes the San Lorenzo River watershed, which contains overlapping habitats of terrestrial, aquatic, and marine species, including 55 species of mammals, 33 species of reptiles and amphibians, and more than 200 species of birds. District-owned lands are home to many of these species, including some of the rarest inhabitants of the sandhills communities. The Santa Cruz Mountains support some of California’s rarest plants and animals including fourteen plants listed as State or Federally threatened or endangered (Morgan et al., 2005). Santa Cruz County has been identified as one of the five most important locations in the U.S. for rare and endangered species (Dobson et. al, 1997). Several species are listed as rare, endemic, threatened or endangered under the federal Endangered Species Act (ESA), the California Endangered Species Act (CESA).

4.1.1 The role of natural disturbance in biodiversity

Disturbance refers to any disruption in the environment that leads to a biological response (Pickett and White, 1985 et al., as cited in Benda et al., 1998). Natural disturbances have shaped the region over the millennia to create its unique landforms, giving rise to its assemblage of habitats and species, and remarkable biodiversity. Because natural disturbances are generally patchy, they tend to shape the landscape into a mosaic of different biological communities, in different states of succession. The resulting abundance of habitats and niches creates a landscape that is more resilient to future disturbances.

Natural disturbances such as fire, storms, floods, landslides, erosion, and earthquakes create new environments. For example, after the ancient sea floor was uplifted over time, and the Miocene sand deposits were exposed to weathering, the resulting erosion created the unique sandhills environment. Today's Zayante sand soils, combined with a maritime climate, gave rise to biological communities found nowhere else in the world. This rare geologic formation occurs throughout the San Lorenzo River watershed, east and west of the Ben Lomond fault, and south of the Zayante fault, and in small isolated patches throughout the rest of the watershed.

Adaptations by species to these new environments can increase biological diversity. For example, the Zayante band-winged grasshopper (*Trimerotropis infantilis)* and the Mount Hermon June beetle (*Polyphylla barbata*) endemic to this area, both adapted to the unique conditions of the sandhills environment (McGraw, 2004).

4.1.2 The role of recent human disturbance

Human disturbance, mostly land-use activities over the last 200 years, has created significant, chronic impacts to plant communities, as well as to wildlife and fisheries habitats. As discussed in the last two sections of this chapter, these impacts have also affected the natural processes that are fundamental to ecosystem function. These processes include the hydrologic or water cycle, nutrient cycle, energy cycle, and ecological community succession.

4.2 Major plant communities of the region, the watershed, and District lands

Plant community classifications and descriptions that follow are partly derived from a publication by Robert Holland of the Department of Fish and Game (Holland, 1986).

The District has not yet mapped and analyzed historical and current vegetation, natural and induced succession, current seral stages of the vegetation or sensitivities to pollution and climate change.

Largely dominated by redwood and mixed evergreen forests, the Santa Cruz Mountains host other major plant communities, including oak woodland, riparian woodland, maritime chaparral, and the endemic sandhills and sand parklands plant communities.

4.2.1 Redwood and mixed-redwood forests

This section provides a description of habitat and range, and attributes of the coastal redwood (*Sequoia sempervirens*) community, with an emphasis on the ecosystem functions of old-growth and late successional forests. The section then describes redwood forest conditions within the San Lorenzo River watershed, and on District lands.

4.2.1.a Habitat and range

Redwood forests are limited to the coast ranges of central and northern California, extending minimally into southern Oregon. Redwoods depend on a coastal maritime climate often with high winter rainfall and a summer stratus layer. When the stratus layer is on the ground, it is called fog, and contributes precipitation to redwoods in the form of fog drip. When the stratus layer is above the tops of the trees, it reduces evapotranspiration levels. The distribution of redwoods is also limited by low temperatures in the winter.

When fog comes in contact with redwoods, it collects on the foliage, condenses, and rolls off the leaves, falling to the ground as fog drip (Haemig, 2003). Dawson (1998) studied heavily fog covered coastal redwood forests of N. California. He found that in summer, when fog was most frequent, 19% of the water within the redwood trees, and 66% of the water within the understory plants came from fog after it had dripped from tree foliage into the soil. Thus, he demonstrated that the trees significantly influence the magnitude of fog water input to the ecosystem. When a redwood forest is cut down, the remaining vegetative community receives less water and summer streamflows within the area are reduced, because of the reduction in fog drip (Haemig, 2003). Open areas without forest cover are also subject to more intense sunlight, which dries out the forest floor.

4.2.1.b Attributes

Haemig (2003) provides a literature review documenting some of the unusual attributes of the coastal redwood:

> According to Sillett and Bailey (2003), large redwood trees are among the most structually complex trees on earth, with individual crowns composed of multiple, reiterated trunks rising from other trunks and branches . . . indistinguishable from free-standing trees except for their origins within the crown of a larger tree (see also Sillett, 1999). For example, Sillet and Van Pelt (2000) studied a single old-growth redwood tree in Redwood National Park and found that its crown had 148 resprouted trunks arising from the main trunk, other trunks, or branches. Five of the resprouted trunks had a basal diameter of over one meter, and the largest resprouted trunk was over 40 meters tall. These researchers concluded that the crown of this redwood could itself be considered a forest.

Each year, redwoods shed some of their foliage. Some foliage falls to the ground, and some foliage accumulates on large branches of the tree, decomposing there into soil known as *canopy soil*. Seeds of plants and spores of fungi colonize canopy soil, eventually creating a plant community high in the canopy of redwood trees (Sawyer et al., 2000). Plants that grow on trees rather than on the ground are called *epiphytes*. Redwood trees often support sizable communities of epiphytes because their large size, great height and complex architecture make them excellent structures for soil and plants to colonize. The complex treetop communities of plants and animals that live in the redwood canopy take many hundreds of years to develop. Some redwood forests, logged in the past 200 years, now contain trees that are big enough to start collecting canopy soils and epiphytes. However, these redwoods are usually felled as timber before their canopy communities become fully developed.

4.2.1.c Redwood and mixed redwood forest of the San Lorenzo River watershed

The plant communities with the highest representation in the San Lorenzo River watershed are redwood and mixed evergreen forests. These communities cover approximately 66,968 acres, or about 74.9% of the San Lorenzo River watershed's land area (San Lorenzo Valley Water District, 1985; Singer, 1979).

Most of the original old-growth redwood (*Sequoia sempervirens*) and Douglas fir (*Psuedotsuga menziesii*) forests in the San Lorenzo River watershed were clear-cut and burned during the late 1800s and early 1900s. Some areas, such as Big Basin and Henry Cowell State Parks, still retain old-growth forests. Patches of old-growth forests and residual old-growth trees are scattered throughout the watershed. However, most of the redwood forest in the San Lorenzo River watershed consists of second-growth or third-growth stands, which sprouted from stumps of the original forest.

Other trees found in local redwood and mixed redwood forests include Douglas fir, tan oak (*Lithocarpus densiflorus*), madrone (*Arbutus menziessi*), and California bay (*Umbellularia californica).* Douglas-fir is a very important component of redwood forests in the Santa Cruz Mountains. It provides the major source of snags and large down logs, and in second-growth forests Douglas fir acquires old-growth characteristics much faster than redwood. Also found, especially in riparian areas, are white alder (*Alnus rhombifolia*), as well as big-leaf maple (*Acer macrophyllum*). Pacific wax myrtle (*Myrica californica*) occurs in redwood forests nearer the coast. Common shrubs include huckleberry (*Vaccinium ovatum*), western azalea (*Rhododendron occidentale*), and California hazelnut (*Corylus cornuta* var. californica). Ferns growing in the redwood forest include western sword fern (*Polystichum munitum*) and giant chain fern (*Woodwardia fimbriata*). Ground covers include redwood sorrel (*Oxalis oregana*), wild ginger (*Asarum caudatum*), redwood violet (*Viola sempervirens*), trillium (*Trillium ovatum*), star lily (*Zigadenus fremontii*) and Pacific Coast iris (*Iris douglasiana).* Fall and winter rains deliver hundreds of kinds of fungi.

At higher elevations, redwoods transition into more drought-tolerant species of the mixed evergreen and chaparral plant communities, which also commonly dominate the drier south-facing slopes.

4.2.1.d Redwood and mixed redwood forest on District land

Redwood and mixed redwood forest covers most of the District's land around its surface water sources, as pictured in Figure 4.1. Some of the District-owned watershed lands contain late successional stands, along with other species noted for the larger watershed. Figure 4.2 shows the undisturbed forest floor on District land, carpeted with redwood sorrel.

Figure 4.1. Typical mixed redwood forest on District-owned watershed land

Herbert 2006

View looking southwest from District-owned property near Malosky Creek, showing typical second-growth redwoods and Douglas fir, interspersed with madrones and native chaparral shrubs.

Figure 4.2. Undisturbed forest floor in a mature forest on District watershed land

Herbert 2006

This forested slope near one of the District's surface water intakes is carpeted with the native redwood sorrel (*Oxalis oregana*).

4.2.2 Black oak woodland plant communities

The deciduous California black oak *(Quercus kelloggii.)* is often found along with interior live oak and canyon live oak in the Santa Cruz Mountains. Preferring hot, dry summers, black oaks are found on ridgetops and in other well-drained areas of the San Lorenzo River watershed, such as in Upper Zayante.

In general, stands of California black oak in the San Lorenzo River watershed are even-aged, originating from some past disturbance such as fire or logging. In the absence of disturbance, black oaks can be overtopped by conifers and eventually replaced because of inherent shade intolerance.

4.2.3 Mixed evergreen forest plant communities

Mixed evergreen forest plant communities occur in the Santa Cruz Mountains, the San Lorenzo River watershed, and on District land. Frequently adjacent to redwood forests, mixed evergreen forests occupy drier and more inland areas, such as Quail Hollow and Zayante. Common trees include Douglas fir (*Pseudotsuga menziesii*), interior live oak (*Quercus wislizenii*), tan oak

(*Lithocarpus densiflora*), madrone (*Arbutus menziesii*), California bay (*Umbellularia californica)*, California buckeye (*Aesculus californica*), and Santa Cruz Mountain oak (*Quercus pavrula* var. *shrevei*). Understory plants include ceonothus, coffee berry, hazelnut, ground rose, and poison oak.

4.2.3.a Sudden oak death

An emergent plant disease, sudden oak death has killed hundreds of thousands of tan oaks and oaks and is dramatically changing the composition of our forests and woodlands. Sudden oak death (SOD) is caused by an invasive non-native water mold, *Phytophthora ramorum*, that first appeared in Marin County in 1995. It subsequently has spread to nearby counties, appearing in Santa Cruz County in 2000. It is now found in all coastal and East Bay Area counties from Humboldt County south to Monterey County, and also in Curry County, Oregon (COMTF 2008).

P. ramorum is the causal agent for two different, but related, diseases – SOD, which is fatal to the tree, and foliar/twig disease which is also known as Ramorum leaf blight and/or Ramorum shoot dieback. SOD affects tan oaks (*Lithocarpus densiflorus*) and most "true" oaks such as coast live oak (*Quercus agrifolia*), interior live oak (*Q. wizlizenii*), Shreve's oak (*Q. parvula* var. *shrevei*), canyon live oak (*Q. chrysolepis*), and black oak (*Q. kelloggii*). Foliar/twig disease is a less virulent disease that affects many other native plant species including coast redwood (*Sequoia sempervirens*), California bay (*Umbellularia californica)*, Douglas-fir (*Pseudotsuga menziesii*), madrone (*Arbutus menziesii)*, bigleaf maple (*Acer macrophyllum*), and a number of native shrubs. *Phytophthora* spores can be found in soil, water, and plant material. The pathogen prefers moist conditions with the risk of movement and spread being greatest during the rainy season. California bay trees are easily infected, and are, for some unknown reason, one of the hosts most effective in spreading the disease. There is no cure for SOD or foliar/twig disease, but the foliar/twig form is not known to be fatal. (COMTF 2008, Davidson et al. 2003).

Tan oaks are especially susceptible to SOD, and once infected, will usually die within 2 – 6 years (Swiecki and Bernhardt 2007). Infected trees can be identified through the following symptoms, not all of which are always present:

1. Sudden browning of all leaves (leaves go from green to brown in 2 – 4 weeks)
2. "Bleeding" spots of dark red to black sticky sap on trunk
3. Frass (looks like sawdust) on the trunk or at base of tree, derived from beetle bore holes in the trunk. Bark beetles are attracted to dying trees, whatever the cause.
4. Black fungi fruiting caps, like small black balls, present on the bark. These are *Hydroxylon* fungi which attack dying trees, whatever the cause.

A two-year study conducted at Point Reyes National Seashore (Moritz et al. 2008), where the first signs of SOD were observed in 2004, reported the following preliminary findings:

- By 2007, 63% of redwood-tan oak stands, 45% of California bay – coast live oak stands, and 24% of Douglas-fir stands were infected by *P. ramorum*.
- Tan oak mortality was greater than 95%, by basal area, in several plots and may have reached 100% in some locales.
- In redwood plots tan oak accounted for an average of one-third of tree species richness and one fifth of total woody species richness. If it were to be eventually eliminated by SOD, the species richness of redwood forests would be severely reduced.
- Mean total fuel loading was greater in diseased redwood plots than in healthy redwood plots.

Tan oaks are the most abundant understory tree in the watershed's redwood forests, and their demise will have ecosystem-changing impacts. They are a prolific producer of acorns which are a major wildlife food item, being utilized by squirrels, chipmunks, deer, woodrats, quail, and band-tailed pigeons, to name a few. These animals and the predators that feed on these animals will be affected, and the ecosystem functions performed by these animals will be impaired. For example, if squirrel numbers are reduced, the dispersal of mycorrhizal fungi may be reduced, this in turn would effect tree growth.

Doug McCreary, Ecologist, U.C. Cooperative Extension's Integrated Hardwood Range Management Program, has pointed out the potentially severe and far-reaching consequences of high levels of oak tree mortality (McCreary, 2001):

> There could be significant impacts to the many wildlife species that are so dependent on coastal oak forests for food and shelter. Deer, turkeys, jays, quail, squirrels, and acorn woodpeckers are just a few of the many species that rely heavily on acorns as a food source. And there are countless other animals that use oak woodland for breeding or as stopover points during migration. Ecological processes such as nutrient cycling, storage and release of water, and moderation of soil temperatures could also be affected. Of more immediate concern, however, is the greatly increased risk of fire resulting from the addition of large quantities of highly combustible fuels. This risk is particularly serious because so much of the coastal forest contains urban interface areas where homes and businesses are nestled among the trees.

4.2.4 Chaparral plant communities

At higher elevations above the fog line, and on south-facing slopes, the mixed redwood forest often transitions into chaparral plant communities, which occupy the hottest and driest slopes of the Santa Cruz Mountains. Chaparral plants thrive on the south-facing slopes and rocky ridgetops of the San Lorenzo River watershed, including District-owned lands.

Chaparral plants form dense thickets comprised of shrub species that are adapted to little water and to wildfire. Leaves of chaparral plants are often small, thick, light green or grayish, and waxy. Leaves are retained year round on most species, but are dropped in summer by others to conserve moisture.

Toyon (*Heteromeles arbutifolia*), coffeeberry (*Rhamnus californica*), ceanothus (*Ceanothus spp.),* Manzanita (*Arctostaphylos spp*.), chaparral pea (*Pickeringia montana*), sage (*Salvia mellifera*.), coyote bush (*Baccharis pilularis*) and chamise (*Adenostoma fasciculatum*) are all well adapted to these dry conditions. Pine (*Pinus attenuata*), golden chinquapin (*Chrysolepis chrysophylla* var. *minor*), and buckeye (*Aesculus californica*) provide taller cover. Chaparral wildflowers are primarily shrubby species including sticky monkey flower (*Mimulus aurantiacus*), Indian paintbrush (*Castilleja sp.)*, California fuschia (*Zauschneria californica*), bush poppy (*Dendromecon rigida*) and yerba santa (*Eriodictyon californicum*).

4.2.5 Plant communities of the Santa Cruz sandhills

Two uncommon communities have been described within the Santa Cruz sandhills: Northern Maritime Chaparral, which includes silverleaf manzanita (*Arctostaphylos silvicola*), and Maritime Coast Range Ponderosa Pine Forest. These plant communities are known locally as *sand chaparral* and *sand parkland*, respectively (McGraw, 2004). Both of these communities have been documented on the District's Olympia watershed property (Harvey & Stanley Associates, Inc., 1983; McGraw, 2004).

4.2.5.a Sand chaparral

Sand chaparral is dominated by shrubs including buck brush (*Ceanothus cuneatus* var. *cuneatus)*, and silverleaf manzanita, which is endemic to the sandhills. Sand chaparral also contains scattered trees, including short-statured coast live oaks and two species of pine: knobcone (*Pinus attenuata*) and ponderosa (*Pinus ponderosa*). Within the gaps in the shrub and tree canopy, sand chaparral supports numerous herbaceous plants, including several species of Navarettia, everlasting nest-straw, Santa Cruz monkeyflower, and the Ben Lomond spineflower (*Chorizanthe pungens var. hartwegiana*), which is also endemic to the sandhills.

4.2.5.b Sand parkland

Sand parkland is an extraordinarily rare community, occurring on fewer than 200 acres in the world. Sand parkland is characterized by a sparse canopy of ponderosa pines surrounded by a diverse assemblage of subshrubs and herbaceous plants. Sand parkland contains the highest diversity and abundance of rare and unique plant species, including the three endemic to the sandhills: the Ben Lomond spineflower (*Chorizanthe pungens ssp. Hartwegiana*), Santa Cruz wallflower (*Erysimum teretifolium*), and Ben Lomond buckwheat (*Eriogonum nudum var. decurrens*).

4.2.5.c Habitat

The permeable, sandy soils of the sandhills limit water availability to vegetation. Evaporation rates are high, and temperatures are extreme, due to the open ecosystem and reflective soil. The origin of the sandhills at the bottom of a Miocene sea is a factor that limits plant growth. Natural compaction in most soils is in the 75-85% range, which permits roots to go deep and support healthy plant growth. However the sea floor was heavily compacted by the weight of billions of gallons of water, resulting in natural compaction that exceeds 100% in some locations. Few species are able to thrive in such heavily compacted sand, but Ponderosa pine and silver-leafed manzanita fare better than most. The veneer of weathered soil that overlies this parent material is so thin it gives rise to an array of unique annuals and perennials (Schlettler, 2008). The sandy soil lacks organic matter and nutrients, and its white color magnifies the temperature of the summer sun (California Native Plant Society, 2007). Plants and animals of the sandhills communities have developed unique adaptations to these features. Many of the plants thrive on soil that is too poor in nutrients for commoner species. Most tend to be annual or to be summer-dormant, growing only in the cooler and moister seasons.

4.2.5.d Range

Located predominantly on steep ridges within the Santa Cruz sandhills, the sandhills community historically encompassed approximately 6,000 acres. Less than 4,000 acres of this rare ecosystem remains in the world, restricted to these sand outcroppings (McGraw, 2004). Of the remaining acreage, only 2,500 acres are of high habitat quality, and only approximately 600 acres are of good habitat quality (McGraw, 2004). Only about 200 acres remains of the rare sand parkland community (McGraw, 2004).

At the ground's surface, sandy soils that form sandhills and sand parkland are found in patchy "islands" of various sizes scattered throughout the Santa Cruz Mountains. Typical sandhills and sand parkland communities can be found in Quail Hollow Ranch County Park, in the District's Olympia watershed land, surrounding existing and abandoned sand quarries, in Scotts Valley, Mt. Hermon, and in patches elsewhere.

Figures 4.3 and 4.4 show plant communities of the sandhills intersecting with riparian woodland on District-owned lands, and interspersed with invasive exotic species including acacia, eucalyptus and French broom.

Figure 4.3 The rare sandhills community at the District-owned Olympia watershed lands

Herbert 2006

Revegetation in the old Ferrari quarry on the District's Olympia Watershed property occurred spontaneously after the closure of the quarry. Ponderosa and knobcone pines, silver-leaf manzanita, and many rare and endangered plants and animals are found in this area, interspersed with invasive exotic species. Rare species have been documented on District lands (McGraw, 2004).

Figure 4.4 Chaparral and riparian woodland habitat at the District-owned Olympia watershed lands

Herbert 2006

Sand chaparral meets riparian woodland near the old Olympia quarry. Here, native golden fleece (*Ericameria ericoides*) is going to seed in late fall. Black cottonwoods (*Populus trichocarpa*) along the creek in the background have dropped their leaves.

4.2.5.e Special status plant species of the sandhills

The sandhills support a unique flora. Many of the plant species composing the community are disjunct coastal species, isolated in the sandhills miles from the coast. Many of these disjunct coastal species even exert different morphologies from their coastal counterparts. The sandhills also contain forms of species that are common elsewhere in the state, but have strikingly different forms or habits than those found elsewhere. Examples are California poppy *(Eschsholzia californica)*, ponderosa pine *(Pinus ponderosa),* and tidy tips *(Layia platyglossa)*.

Both sand chaparral and sand parklands are home to many threatened and endangered plants. Table 4.1 lists these special status species.

Table 4.1 Special status plant species of the sandhills and sand parkland habitats

Common name	Species name	Status
Silver leaf manzanita	*Arctostaphylos silvicola*	Endemic to sandhills
Santa Cruz cypress	*Cupressus abramsiana*	State endangered; Federally endangered
Santa Cruz monkey flower	*Mimulus rattanii decurtatus*	Rare; endemic to California
Ben Lomond buckwheat	*Eriogonum nudum var. decurrens*	Endemic to sandhills
Ben Lomond wallflower	*Erysimum teretifolium*	Endemic to sandhills; Federally protected
Ben Lomond spine flower	*Chorizanthe pungens ssp. hartwegiana*	Endemic to sandhills; Federally protected

Source: McGraw, 2004.

4.2.5.f Loss of sand chaparral and sand parkland communities

Most losses of sand chaparral and sand parkland have occurred due to open pit mining in the watershed and on District-owned lands (before the District acquired these lands). Houses and roads have also been built upon the rare and fragile ecological community.

Sand chaparral and sand parkland are very fragile, and extremely susceptible to disturbance. Disturbance from off-road vehicles, mountain biking, horseback riding and even foot traffic can severely damage and alter the vegetative community. All of these activities occur on the District-owned lands. For more information about the impacts of recreational uses, refer to Chapter 6. In addition, invasive plant species such as French broom and acacia are present on the District-owned Olympia watershed lands, where they compete with endangered species for limited habitat. These areas are extremely susceptible to adverse affects of erosion and concentrated runoff, as is discussed in Chapter 3, Hydrology, Geomorphology, and Water Quality.

4.2.6 Riparian woodland plant communities

The riparian woodland plant communities generally form a linear corridor along both sides of a stream (lotic aquatic environment), or surrounding a lagoon or lake (lentic aquatic environment). Riparian vegetation may be defined as “any extra-aquatic vegetation that directly influences the stream environment by providing shade, large debris, or fine litter” (Meehan et al., 1977). Thus, trees growing above the floodplain on terraces and hill slopes are considered riparian, if they influence shading and/or may be a source of energy and large woody material to the stream.

4.2.6.a Riparian woodland in the San Lorenzo River watershed

Several local riparian forest types may combine to form the riparian corridor, and they are commonly interspersed with other woody and shrubby species, including redwood trees. Native deciduous trees common to the riparian corridor in the San Lorenzo River watershed may include species of willow (*Salix spp.*), alder (*Alnus spp.*), black cottonwood (*Populus balsamifera* subspecies *trichocarpa*), California sycamore (*Plantus racemosa*), big leaf maple (*Acer macrophyllum*), creek dogwood (*Cornus sericea*), and California box elder (*Acer negundo*).

4.2.6.b Riparian woodland on District-owned land

Figure 4.5 depicts riparian woodland above the District’s Quail Hollow Well.

Figure 4.5 Riparian woodland in Quail Hollow above the District's well.

Herbert 2006

Black cottonwood *(Populus balsamifera ssp. Tricocarpa)* and Douglas fir (*Pseudotsuga menziessi*) shade the creek between the District's two active Quail Hollow wells.

4.2.7 Grassland plant communities

Much of the region's coastal prairie has been destroyed due to agriculture and development, The remaining areas have been invaded by exotic weeds such as annual ryegrass (*Lolium multiflorum*), wild oats (*Avena fatua*), annual fescues (*Vulpia bromoides*), bromes (esp. *Bromus diandrus*), velvet grass (*Holcus lanatus*), and thistles (esp. *Carduus pycnocephalus*). The remaining, in tact areas of coastal prairie are recognized by the presence of California oatgrass (*Danthonia californica*) and/or wildflowers, such as native bulbs (*Brodiaea* and *Triteleia* species), lupines (*Lupinus nanus*), self-heal (*Prunellus vulgaris*), and many others. The best areas to view coastal prairie are at UCSC's upper campus (Marshall Meadows), State Parks' Gray Whale Ranch, and just north of Año Nuevo along the coast south of Franklin Point.

4.2.8 Other endemic, rare, and endangered plant species of the region

The coast rock cress (*Arabis blepharophylla*) occurs on rocky coastal bluffs, bare granitic soils, and open grassy slopes on the coastal side of the Santa Cruz Mountains. Thomas (1961) found coast rock cress near Boulder Creek. The San Francisco wallflower (*Erysimum franciscanum var. franciscanum*) was found near Forest Park by the California Native Plant Society (San Lorenzo Valley Water District, 1985).

Table 4.2 lists species on the federal Endangered Species List, known to inhabit the San Lorenzo River watershed or elsewhere in the county.

Table 4.2. Listed threatened and endangered species in Santa Cruz County

Common name	**Latin name**	**Status***
Plants		
Ben Lomond spineflower	*Chorizanthe pungens* var. *hartwegiana*	FE
Ben Lomond wallflower (also called Santa Cruz wallflower)	*Erysimum teretifolium*	FE, SE
Monterey spineflower	*Chorizanthe pungens* var. *pungens*	FT
Robust spineflower	*Chorizanthe robusta* var. *robusta*	FE
Santa Cruz cypress	*Cupressus abramsiana*	FE, SE
Santa Cruz tarplant	*Holocarpha macradenia*	
Scotts Valley polygonum	*Polygonum hickmanii*	FE, SCE
Scotts Valley spineflower	*Chorizanthe robusta* .var. *hartwegii*	FE
Tidestrom's lupine (clover lupine)	*Lupinus tidestromii*	SE
White-rayed pentachaeta	*Pentachaeta bellidiflora*	FE, SE
Invertebrates		
Smith's blue butterfly	*Euphilotes enoptes smithi*	FE
Mt. Herman June beetle	*Polyphylla barbata*	FE
Ohlone tiger beetle	*Cicindela ohlone*	FE
Zayante band-winged grasshopper	*Trimerotropis infantilis*	FE
Fish		
Coho salmon-central California ESU	*Oncorhynchus kisutch irideus*	FE, SE
Steelhead-central California ESU	*Oncorhynchus mykiss irideus*	FT
Tidewater goby	*Eucyclogobius newberryi*	FE
Amphibians		
Santa Cruz long-toed salamander	*Ambystoma macrodactylum corceum*	FE, SE
California tiger salamander	*Ambystoma californiense*	FT
California red-legged frog	*Rana aurora draytonii*	FT
Reptiles		
San Francisco garter snake	*Thamnophis sirtalis tetraenia*	FE, SE
Birds		
Western snowy plover	*Charadrius alexandrinus nivosus*	FT
Bank swallow	*Riparia riparia*	ST
Marbled murrelet	*Brachyramphus marmoratus*	FT, SE
California black rail	*Laterallus jamaicensis coturniculus*	ST
American peregrine falcon	*Falco peregrinus anatum*	SE

Sources: Morgan and the Santa Cruz Flora Committee, CNPS, 2005..
California Department of Fish and Game, 2008
FE= Federally listed, Endangered; FT=Federally listed, Threatened;
SE= State-listed Endangered; ST=State-listed, Threatened
SCE= State-listed, candidate Endangered

If the above list included species that historically inhabited the watershed, it would be considerably longer. While no bat species are listed under the Endangered Species Act, many species of bats are considered a species of special concern. Table 4.3 lists bat species that have been observed in the San Lorenzo River watershed.

Table 4.3. Status of bat species observed in the San Lorenzo River watershed

Family VESPERTILIONIDAE (Plain-nosed or mouse-eared bats)		
Common name	**Latin name**	**Status**
Little brown myotis	*Myotis lucifugus*	
Yuma myotis	*Myotis yumanensis*	**FSC/CSC/BLMS**
Long-eared myotis	*Myotis evotis*	**FSC/BLMS**
Fringed myotis	*Myotis thysanodes*	**FSC/BLMS/WBWG**
Long-legged myotis	*Myotis volans*	**FSC/BLMS/WBWG**
California myotis	*Myotis californicus*	
Silver-haired bat	*Lasionycteris noctivagans*	
Big brown bat	*Eptesicus fuscus*	
Western red bat	*Lasiurus blossevillii*	**FSS/WBWG**
Hoary bat	*Lasiurus cinereus*	
Townsend's big-eared bat	*Corynorhinus townsendii*	**FSC/CSC/FSS/BLMS/WBWG**
Pallid bat	*Antrozous pallidus*	**CSC/FSS/BLMS/WBWG**
Family MOLOSSIDAE (Free-tailed bats)		
Mexican free-tailed bat	*Tadarida brasiliensis*	

FSC = Federal Special Concern species (former Category 2 candidates for ESA listing)
CSC = California Department of Fish and Game's California Special Concern species
FSS = Forest Service Sensitive species
BLMS = Bureau of Land Management Sensitive species
WBWG = Western Bat Working Group High Priority species

Source: Table adapted from table provided by Paul A. Heady, Biologist and California Department of Fish and Game.

4.3 Wildlife species of the region, the watershed, and District lands

This section describes the wildlife species of the Santa Cruz Mountains, which are also known to occur in the San Lorenzo River watershed, and probably occur on District lands, although District lands have not been surveyed. Species are grouped by the plant communities on which they depend, including redwood forests, old-growth and late successional redwood forests, riparian woodland, and chaparral.

The District has not conducted a wildlife habitat analysis, using the California Wildlife Habitat Relationships System, on its watershed lands.

4.3.1 Wildlife species of redwood and mixed redwood forest communities

Native understory plants, such as blackberry, huckleberry, and California hazelnut, with abundant fruit and seeds, provide forage for wildlife. The natural cavities in old-growth redwood trees provide nest sites for birds, cover for small mammals, and roosting areas for bats. The cool, damp microclimate of redwoods attracts more amphibians than the drier mixed evergreen forest.

The City of Santa Cruz (Swanson Hydrology & Geomorphology, 2001) lists some of the wildlife species supported by mixed redwood throughout their 3,880 acre holdings in the San Lorenzo River watershed:

> Representative amphibians that inhabit redwood forests include rough-skinned newt (*Taricha granulosa*), ensatina (*Ensatina eschscholtzii*), Pacific giant salamander (*Dicamptodon ensatus*) and arboreal salamander. Typical year-round resident birds include Steller's jay (*Cyanocitta stelleri*), common raven (*Corvus corax*), northern saw-whet owl (*Aegolius acadius*), pileated woodpecker (*Dryocopus pileatus*), hairy woodpecker (*Picoides villosus*), pygmy nuthatch (*Sitta pygmaea*), brown creeper (*Certhia americana*), winter wren (*Troglodytes troglodytes*), chestnutbacked chickadee, golden-crowned kinglet (*Regulus satrapa*), dark-eyed junco (*Junco hyemalis*) and purple finch. Usual summer residents include, Pacific-slope flycatcher, hermit thrush and hermit warbler (*Dendroica occidentalis*), while winter residents consist of ruby-crowned kinglet, varied thrush (*Ixorues naevius*) and Townsend's warblers. Representative redwood forest mammals include Trowbridge's shrew (*Sorex trowbridgii*), shrew-mole (*Neurotrichus gibbsii*), broad-footed mole, long-eared myotis (*Myotis evotis*), western gray squirrel, raccoon and black-tailed deer.

Steller's jay (*Cyanocitta stelleri*) and Swainson's thrush (*Catharus ustulatus*) are more abundant on the edges of redwood forests than the interiors, while the varied thrush (*Ixorcus naevius)*, brown creeper (*Certhia americana*), winter wren (*Troglodytes troglodytes*), and Pacific-slope flycatcher (*Empidonax difficilis*) are more abundant in the interior of redwood forests than the edges (Brand and George, 2001). Predation of bird nests appears to be greater on the edges of redwood forests than the interior. In a study using artificial nests with quail eggs, Brand and George (2000) found that the chances of the nest being found and eaten by a predator decreased as the distance from the forest edge increased, up to a distance of 115 meters from the forest edge.

4.3.2 Wildlife species of old-growth and late-successional redwood forest communities

Only 4% of the original ancient coast redwood forest remains. The other 96% has been logged within the last 200 years (Hunter and Bond, 2001). Scattered old-growth redwood trees that were not cut during the original large-scale logging are called "residual trees" by wildlife managers. These trees provide important habitat structures that certain species of wildlife need and which younger second-growth trees don't provide. According to Hunter and Bond (2001):

> These individual large residual trees or small stands of residual trees are often the only remaining complex structural elements in a matrix of younger forest. As such, they provide the best foraging, resting, and breeding sites for wildlife normally associated with older forests.

Old-growth forests support abundant biodiversity. They provide breeding habitat necessary for such bird species as spotted owl, pileated woodpecker, the federally listed marbled murrelet, the federally listed northern spotted owl, golden-crowned kinglet, hermit warbler, Vaux's swift, and purple martin.

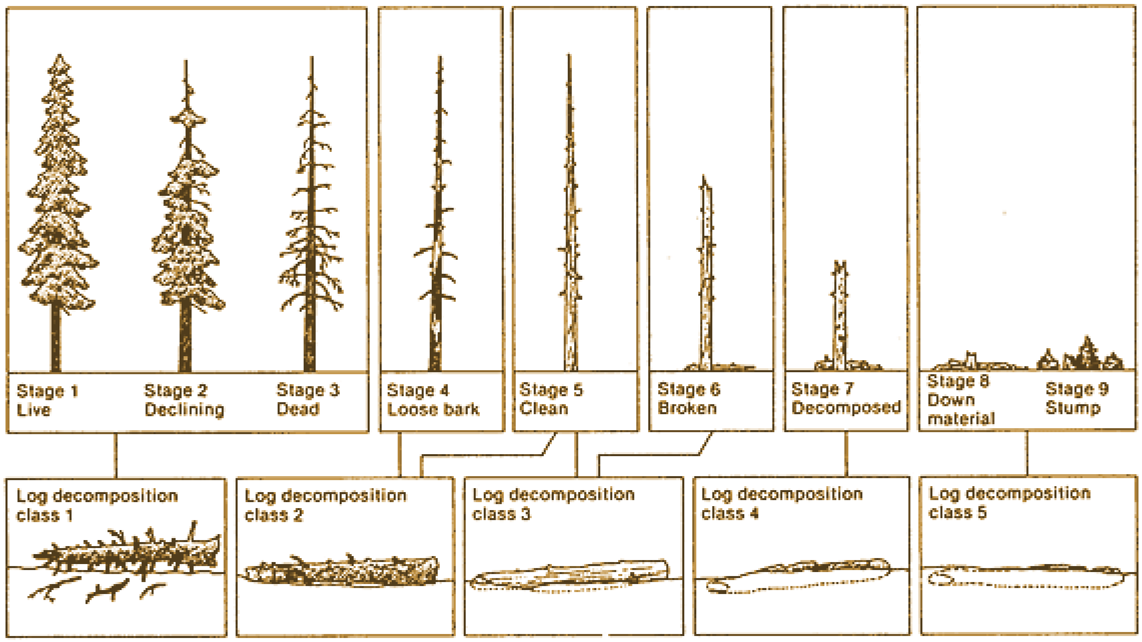
Animals including beetles, crickets, earthworms, millipedes, mollusks, arthropods and amphibians colonize the soils and plant communities of the redwood canopy (Sawyer et al., 2000; Sillett and Bailey, 2003). One noteworthy animal is the clouded salamander (*Aneides* *vagrans*), the only salamander species outside the New World tropics known to live entirely in tree canopies (Cooperrider et al., 2000).

Many species of birds nest high in the canopy of old-growth redwood trees. These include peregrine falcons (*Falco peregrinus*), bald eagles (*Haliaeetus leucocepahlus*), marbled murrelets (*Brachyramphus marmoratus*), northern spotted owls (*Strix occidentalis caurina*) and the fisher (*Martes pennanti*) (Binford et al., 1975; Hunter and Bond, 2001; Cooperrider et al., 2000). In addition, Vaux's swift (*Chaetura vauxi*) nests and roosts inside old, hollow redwood trees (Sterling and Paton, 1996). The California condor (*Gymnogyps californianus*) possibly nested in the redwood canopy, as well. Two hundred years ago, this giant bird was common along the coast of northern California, but was extirpated there before ornithologists could study it. In the Sierra Nevada, where the condor survived much longer, ornithologists found it nesting in cavities of the giant sequoia (*Sequoiadendron giganteum*), a tree related to the coast redwood (Koford 1953; Snyder et al. 1986).

Many birds and some mammals nest or den in cavities or spaces under bark of snags, as illustrated in Figure 4.6. Birds nest in primary or secondary cavities. Primary cavity dwellers, such as woodpeckers, excavate their own holes. Secondary cavity dwellers use abandoned holes or drive off primary cavity dwellers to use their nests. The space behind lifted bark also provides rookeries (nesting habitat) for such birds as the brown creeper (*Certhia americana*), as well as roosting and nesting habitats for bats. Larger owls and birds of prey are dependent upon platforms atop snags or live trees for nesting. Reductions in snags will reduce populations of cavity dwelling species.

Many birds and mammals depend upon snags as food sources. Woodpeckers pick insects off all parts of dead and dying trees. Acorn woodpeckers, found throughout the San Lorenzo River watershed, use snags and sometimes live trees as *granaries* (food storage banks) to store acorns and attract insects to feed upon later. Snags host many different fungi, which are food sources for some insects and small mammals. The increased insect densities associated with snags provide food for bats and many bird species.

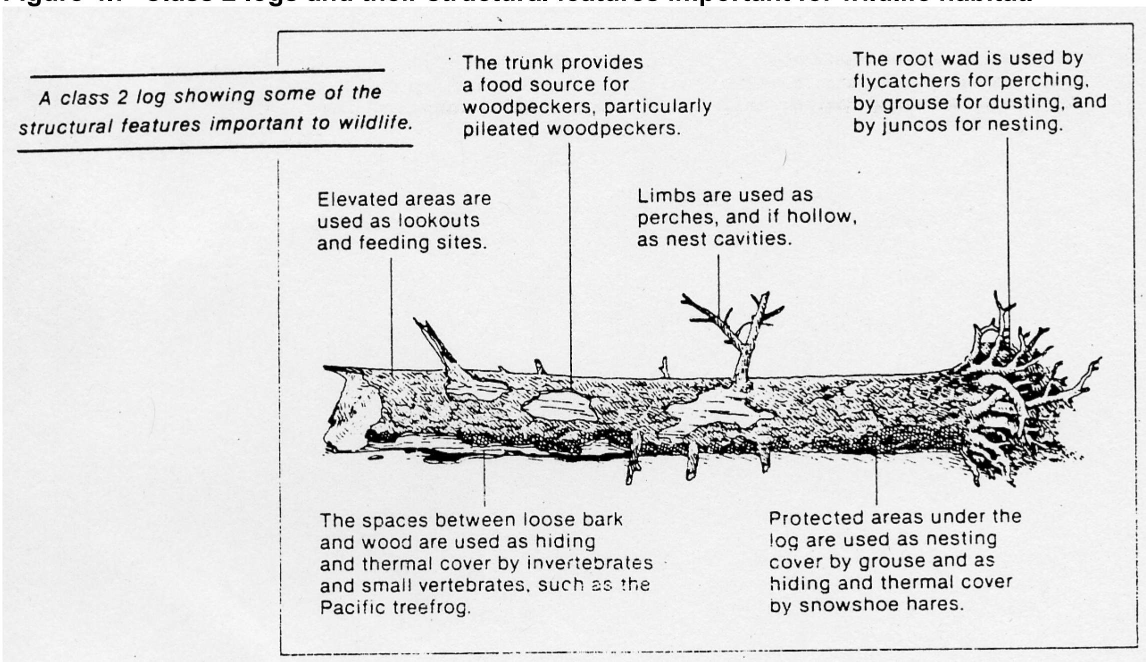
Figure 4.6 Stages of standing snags, and classes of decomposition of downed logs.



Source: Bull, et al., 1997.

Downed logs on the forest floor also provide valuable habitat for wildlife. Figure 4.7 depicts the important structural features for habitat of Class 2 logs. Class 1 is more structurally sound, upright and generally has more intact branches and bark than more decayed classes. As the log progresses through the stages of decay, its structural integrity is slowly lost, and its habitat type becomes more suitable to smaller animals. As it decays further, its habitat type becomes more suitable to plants and fungus than to animals. Eventually, the log decomposes into the duff layer of the soil. The more decayed logs of Class 3 and Class 4 have 1.5 more nitrogen than live wood (Maser et al., 1979).

Figure 4.7 Class 2 logs and their structural features important for wildlife habitat.



Source: Maser et al., 1979.

Large downed logs provide habitat for many wildlife species. Some species rely on downed logs as their primary habitat. Logs of at least 15 inches in diameter are particularly important to species such as the pileated woodpecker (Bull et al., 1997). In the United States, more than 1,200 wildlife species rely on dead, dying, or hollow trees, and logs for dens, roost areas, and feeding sites (Maser et al., 1979).

4.3.3 Wildlife species of riparian plant communities

Riparian plant communities support an especially high degree of biological productivity. The wide variety of plant species provides a large food base for wildlife. Riparian vegetation is generally dense, providing cover from predation. The dense, lush vegetation and presence of water in riparian habitat also creates a mild microclimate. Stratified vegetation within the riparian zone provides various ecological niches. Most terrestrial wildlife species use riparian zones when available, and some reside only within riparian zones. Riparian habitat is an important breeding habitat for many species.

Throughout the state of California, the riparian zone provides one of the most important habitats for wildlife. The California Department of Fish and Game stated that riparian habitat provides living conditions for a greater variety of wildlife than any other habitat type (San Lorenzo Valley Water District, 1985). Riparian zones support the most diverse and abundant avifauna in California (Small et al., 1998).

The most direct link between terrestrial and aquatic ecosystems occurs in the riparian zone, and consequently, the health of aquatic ecosystems is inextricably tied to the integrity of the riparian zone (Spence et al., 1996). Riparian zones are linear, and are used by wildlife as corridors, which are important in connecting fragmented habitats created by rural land disturbance.

4.3.4 Wildlife species of chaparral plant communities

Denser stands of chaparral plants are especially suited to secretive wildlife species that seek extensive cover (Swanson Hydrology & Geomorphology, 2001). More open areas provide look-outs for predator species, and less cover for prey. More structural complexity is provided in areas where chaparral is interspersed with trees. These areas provide the most habitat value.

A wide variety of reptiles make use of chaparral plant communities. Prey populations of rodents and invertebrates provide foraging resources, while rock outcrops and the abundance of low-growing shrubs offer excellent cover, sunning, and territorial display sites (Swanson Hydrology & Geomorphology, 2001). Common wildlife expected to inhabit the chaparral habitats include western fence lizard (*Sceloporus occidentalis*), California whipsnake (*Masticophis lateralis*), and western rattlesnake (*Crotalus viridis*). Chaparral supports a limited number of year-round bird species, including wrentit (*Chamaea fasciata*), Bewick's wren (*Thryomanes bewickii*), California towhee (*Pipilo crissalis*), spotted towhee (*P. maculatum*), California thrasher (*Taxostoma redivivum*), and scrub jay (*Aphelocoma coerulescens*). Manzanitas are an important nectar source for hummingbirds. Summer resident birds may include Anna's hummingbird (*Calypte anna*), Allen's hummingbird (*Selasphorus sasin*), and blue-gray gnatcatcher (*Polioptila caerulea*). Winter residents may include fox sparrow (*Passerella iliaca*), white-crowned sparrow (*Zonotrichia leucophrys*) and golden-crowned sparrow (*Zonotrichia atricapilla*).

Mammal species that prefer dense chaparral may include brush rabbit (*Sylvilagus bachmani*), deer mouse (*Peromyscus maniculatus*) and brush mouse (*Peromyscus boylii*). Predatory species that forage in dense chaparral include bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), and spotted skunk (*Spilogale putorius*). Coyotes (*Canis latrans*) forage in open, disturbed areas of chaparral.

4.3.5 Wildlife habitat and species of the Santa Cruz sandhills

Federally endangered animals endemic to the Santa Cruz sandhills, such as found on the District's Olympia watershed property, include the Mt. Hermon June beetle *(Polyphylla barbata)*, the Zayante band-winged grasshopper *(Trimerotropis infantilis),* and the Smith's blue butterfly *(Euphilotes enoptes smithi)*. Other animals that inhabit the sandhills include the rare Western whiptail lizard *(Cnemidophorus tigris)*, and the coast horned lizard *(Phrynosoma croronatum).* The Santa Cruz kangaroo rat *(Dipodomys venustus)* is endemic to the sandhills communities. It was found extensively throughout the Olympia property in 1984 by a student doing her senior thesis (Haynes, 2006), but has not been found since (McGraw, 2004). Plants endemic to the sandhills include the characterizing silver leaf manzanita *(Arctostaphylos silvicola)* and the Ben Lomond wallflower *(Erysimum teretifolium).* Federally protected plants that are restricted to sandhills include Ben Lomond spineflower *(Chorizanthe pungens ssp. hartwegiana)*, and Ben Lomond wallflower *(Erysimum teretifolium)*.

Sand parkland is also home to the sandhills endemic insects: the Mt. Hermon June beetle and Zayante band-winged grasshopper. In addition, sand parkland contains populations of the coast horned lizard and western whiptail lizard, which are far away from the next nearest populations.

Table 4-4 lists special status species of the sandhills community.

Table 4.4 Special status animal species of the Santa Cruz sandhills

Common name	**Species name**	**Status**
Western whiptail lizard	*Cnemidophorus tigris*	Locally rare
Coast horned lizard	*Phrynosoma coronatum*	Locally rare
Santa Cruz kangaroo rat	*Dipodomys venustus*	none
Greater roadrunner	*Geococcyx californianus*	extirpated
Mt. Hermon June beetle	*Polyphylla barbata*	Endemic to sandhills; Federally endangered
Zayante band-winged grasshopper	*Trimerotropis infantilis*	Endemic to sandhills; Federally endangered
Smith's blue butterfly	*Euphilotes enoptes smithi*	Federally endangered

Source: McGraw, 2004; Singer, 2008.

Table 4.5 lists special status wildlife species and their predicted occurrence on the City of Santa Cruz watershed lands.

Table 4.5 Special status wildlife species and their predicted occurrence on the City of Santa Cruz watershed lands

Species	Status[1]	Habitat[2]	Occurrence on site
Amphibians			
California red-legged frog *Rana boylii*	FT, CSC	Riparian, marshes, and ponds.	Observed at Mountain Charlie Creek,* Bull Creek,* upper Bean Creek;* possible in Laguna Creeks; occurrence in Newell Creek unknown.
Foothill yellow-legged frog *Rana boylii*	CSC	Creeks, rivers with cobble substrate.	Possible in Laguna, Zayante Creeks. Occurrence in Newell Creek unlikely.
Reptiles			
Southwestern pond turtle *Clemmys marmorata pallida*	FSC, CSC	Creeks and ponds.	Occurs in Loch Lomond Reservoir and Newell Creek.
California horned lizard *Phrynosoma coronatum frontale*	FSC, CSC	Chaparral with loose soils	Possible in Laguna Creek unit adjacent to Bonny Doon preserve.
California whipsnake *Masticophis lateralis*	SFB	Chaparral, valley-foothill riparian, oak, conifer	Possible.
Birds			
Cooper's hawk *Accipiter cooperii*	CSC	Oak woodland, riparian and mixed forests	Potential nesting habitat in mixed evergreen and oak woodlands.
Sharp-shinned hawk *Accipter striatus*	CSC	Nests in coniferous forests	Potential nesting habitat in redwood, Douglas fir forests.
Golden eagle Aquila chrysaetos	CSC	Nests in oak woodland	Possibly may nest in or near the Laguna Creek unit.
Bald Eagle *Haliaeetus leucocephalus*	SE, FT	Forages at Loch Lomond Reservoir	Occasional winter visitor in the Newell Creek unit.
Osprey *Pandion haliaetus*	CSC	Forages at Loch Lomond Reservoir	Regular year-round visitor to the Newell Creek unit.
Merlin *Falco columbarius*	CSC	Winters in the county in a variety of habitats	Likely winters in a variety of habitats.
Long-eared owl *Asio otus*	CSC, SFB	Riparian forests and woodlands adjacent to open foraging areas; requires old nests of other hawks or squirrels	Potential nesting habitat in mixed forests where live oaks are predominant.
Vaux's swift *Chaetura vauxi*	CSC	Nests in hollow of old growth or mature second growth redwood and Douglas fir trees	Potential nesting habitat in mature forests.
Purple martin *Progne subis*	CSC	Nests in cavities of mature trees (e.g., knobcone pines with woodpecker holes, sometimes in chimneys	Potential nesting habitat in knobcone pine forests.
(Continued on next page)			

Table 4.5 Special status wildlife species and their predicted occurrence on the City of Santa Cruz watershed lands (continued)

Species	Status[1]	Habitat[2]	Occurrence on site
Mammals			
Shrew-mole *Neurotrichus gibbsi*	SFB	Redwood forests, other moist forests	Possible
Pallid bat *Antrozous pallidus pacificus*	CSC	Wide variety of habitats; roosts in caves crevices, mines, hollow trees, buildings	Possible
Fringed myotis *Myotis thysanodes*	FSC, SFB	Redwood forests along west coast	Possible
Yuma myotis *Myostis yumanensis*	FSC, CSC	Open forests and woodlands with water nearby; roosts in buildings, caves, crevices	Possible
Townsend's western big-eared bat *Corynorhinus townsendii townsendii*	FSC, CSC	Wide variety of habitats; roosts in caves, tunnels, mines, and buildings	Possible
Santa Cruz kangaroo rat *Dipodomys venustus venustus*	SFB	Maritime chaparral with sandy soils	Possible in Laguna Creek unit adjacent to Bonny Doon preserve.
San Francisco dusky-footed woodrat *Neotoma fuscipes annectens*	FSC, CSC	Riparian and oak woodlands	Observed; likely common inhabitant of woodlands.
Mountain lion *Felis concolor*	*, SFB	Variety of habitats, chaparral may be primary; needs large undeveloped territory	Lion tracks and scat observed on trail in Bonny Doon preserve adjacent to Laguna Creek unit.

Source: City of Santa Cruz, Watershed Resources Management Plan, Existing Conditions Report, 2002.

*California Dept. of Fish and Game, Natural Diversity Database, 2008.

[1] Key to status:
FC = Federal candidate for listing as endangered
FE = Federally listed as endangered species
FT = Federally listed as threatened species
FSC = Federal species of special concern
SE = State endangered
CSC = California species of special concern
SFB = Sensitive fauna in the Santa Cruz Mountains Bioregion.

[2] Type of habitat listed for each species refers only to those habitat types that occur on watershed lands, although elsewhere the species may occur in other habitat types.

4.4 Aquatic habitat and fisheries of the region, the watershed, and District lands

A stream is a complex living system. A healthy stream bed interacts with dissolved nutrients and organic matter in the flowing water to create a dynamic environment, rich with plant and animal life (County of Santa Cruz, 2003). Characteristics of a streambed that influence this dynamic environment include composition, its gradient, and its shape.

4.4.1 Characteristics of a healthy stream

Streams reflect what is happening on the surrounding land. A healthy stream has the following characteristics:

- Cool, clear oxygen-rich water free of pollutants and excess algae.
- Gravel and cobble without too much sand and silt for aquatic insect production and fish spawning.
- Fastwater habitat (riffles and runs) for aquatic insects and foraging fish.
- Frequent pool tail-riffle transitions (glides) for spawning salmonids.
- Deep pool habitat for foraging fish with adequate escape cover for fish to hide from predators and overwintering cover for fish to find shelter behind during high flows.
- A balance of fast water riffles for aquatic insects, fish spawning and feeding, and pool habitats as cover and refuge from high flows.
- Abundant woody material to provide habitat and cover for aquatic and riparian species, and to scour pools.
- Adequate summer streamflow.
- Lush streamside vegetation to stabilize streambanks and provide shade, escape cover for fish and food for wildlife and fish (County of Santa Cruz, 2003; Alley, 2008).

The health of the stream environment depends on several physical factors: water quality; water temperature; the amount of sunlight reaching the stream; the character of the stream bottom (whether bedrock, boulder, gravel, sand, or fine silt); and the volume and timing of water flowing through the stream. Human activities can influence all of these characteristics. Riparian habitats provide food and shelter for a great variety of wildlife. This zone is also critical as a migration corridor for birds and terrestrial mammals, especially where nearby upland development can be a barrier to overland travel.

Coastal streams, such as the San Lorenzo River, are also important for their tidally influenced estuaries during the wet season and freshwater lagoons that develop in summer once sandbars close at their rivermouths. This highly productive fish habitat requires adequate perennial (year-round) streamflow of high water quality and the avoidance of artificial sandbar breaching."

Freshwater lagoons provide valuable steelhead nursery habitat. Freshwater lagoons, which have closed sandbars, are distinct from saline estuaries, which have open sandbars and are tidally influenced. Some would like to breach the summer sandbar at the rivermouth, which would destroy steelhead habitat. Sandbars should be allowed to form in the summer and for lagoons to convert to freshwater with adequate inflow (County of Santa Cruz, 2003; Alley, 2008).

The creeks and tributaries of the San Lorenzo River are home to many aquatic species including invertebrates, fish, reptiles and amphibians, and other aquatic organisms. Many terrestrial mammal and bird species also rely upon aquatic habitats and aquatic prey species.

The San Lorenzo River serves as both a sink and a source of nutrients. It continually receives nutrients primarily from groundwater and eroded soil during storm runoff from adjacent upslope areas, both forested and developed. The river and its tributaries remove inorganic and organic materials from the landscape by water transport. This process contributes to the shape and dimensions of the stream itself. Stream *morphology* is strongly affected by geologic, hydrologic and land-use characteristics and histories, because these factors directly influence the sedimentation rate to the stream and the sediment transport rate by the stream.

4.4.2 The food web in aquatic ecosystems

Riparian vegetation provides much of the organic litter required to support biotic activity within the stream, as well as the large woody debris, which is a key component of aquatic habitat (Spence et al., 1996).

Leaves from the surrounding forest and *riparian zones* provide the energy for the *benthic macroinvertebrate* (BMI) community. In areas of the watershed where sunshine easily reaches the stream bottom, instream photosynthesis begins to play an important role. As deciduous riparian leaves enter streams in the fall, various leaf-mining and leaf-shredding aquatic insects begin to ingest them. As leaves are decomposed by fungi and bacteria, other aquatic insects and macroinvertebrates collect and consume leaf fragments and their microbes often from drifting detritus. Thus, leaves form the energy base for the stream ecosystem.

Adult aquatic insects are vulnerable to predation by other insects, fish, mammals, birds, reptiles and amphibians. In this fashion, streams also provide energy resources to the adjacent terrestrial ecosystems.

Shredder organisms consume leaves, twigs and other large pieces of *detritus*. Biologists have shown that, at least in some instances, these animals may gain as much nutrition from the fungal and bacterial colonies in the detritus as from the wood or leaf itself. Feces and undigested detritus are then in turn food for other organisms, or dissolve into the water. *Collector-gatherer* organisms, such as insects and crustaceans, search benthic areas for the larger material. *Filter-collectors,* such as caddisflies, strain the smaller material from the flowing water of the stream. *Scraper-collectors,* such as snails, are most common in areas of a stream that receive direct sunlight in the summer. They consume the fungi and bacteria that feed on algae, which colonizes every available surface in the stream. *Predators* are at the 'top' of the food chain. These include a few insect larvae which crawl around on the stream bottom and attack smaller insects. Dragonfly larvae may sit and wait near a bank or in shallow, silt-covered areas.

In healthy streams, the relative abundance of these various types of organisms in the benthic macroinvertebrate (BMI) community varies with the size of the stream, which largely determines the abundance of food resources and type of habitat. For example, in small headwater streams, shredder organisms are generally more abundant than scraper organisms. Filter-feeders are generally more prevalent in mid-sized streams. However, the ratio of predators to other organisms remains more stable, no matter what the size of the stream.

The California Stream Bioassessment Procedure (CSBP) is a standardized protocol for assessing biological and physical/habitat conditions of wadeable streams in California. The CSBP is a regional adaptation of the national Rapid Bioassessment Protocols outlined by the U.S. Environmental Protection Agency in "Rapid Bioassessment Protocols for use in Streams and Rivers" (US EPA, 1989). The CSBP utilizes measures of a stream's benthic macroinvertebrate (BMI) community and its physical/habitat characteristics to determine the stream's biological and physical integrity. BMIs can have a diverse community structure with individual species residing within the stream for a period of months to several years. They are also sensitive, in varying degrees, to temperature, dissolved oxygen, sedimentation, scouring, nutrient enrichment and chemical and organic pollution. Biological and physical assessment measures integrate the effects of water quality over time, are sensitive to multiple aspects of water and habitat quality and can provide the public with a familiar expression of ecological health.

Scientists are using CSBP in stream and forest restoration projects, to evaluate biological stream recovery following watershed restoration efforts in Redwood National Park (US Geological Survey, 2007). The study will also model various restoration scenarios to determine the most effective strategy for stream improvement.

4.4.3 Large instream wood as a component of aquatic habitat

Instream wood forms complex habitat for aquatic species, including Federal or State listed threatened or endangered species, such as coho salmon, steelhead and California red-legged frogs.

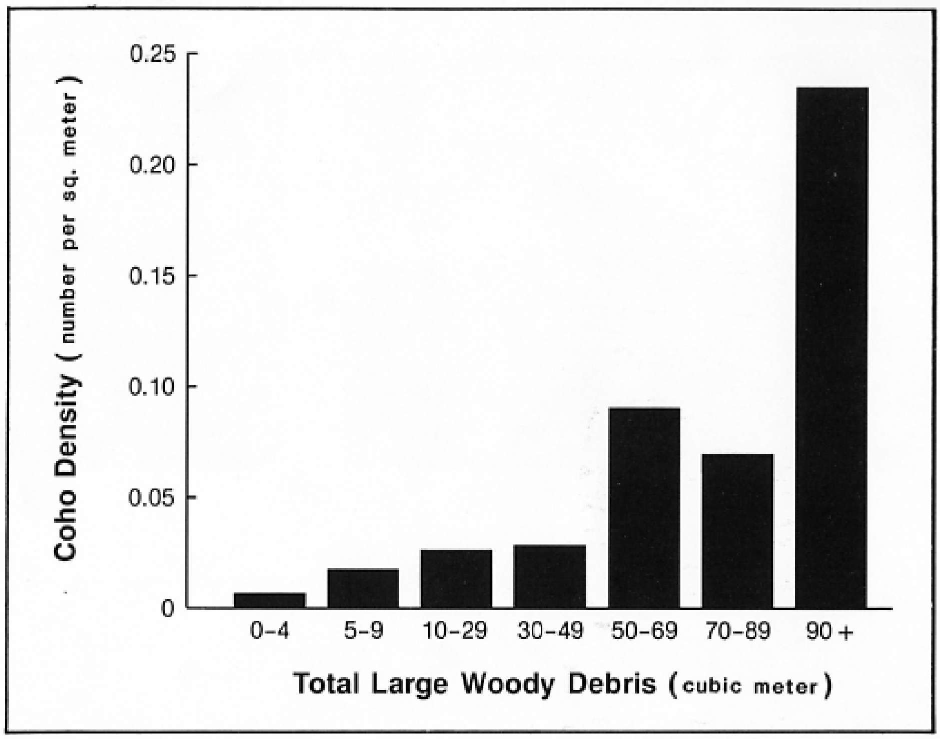
In their research within coastal redwood forests, Keller et al. (1981) found that some instream logs had been in place for over 200 years. Instream wood can provide stable channel and habitat benefits for centuries (Keller et al., 1981; Napolitano, 1998; Benda and Sias, 2002). The wood slowly decays while it remains instream. Organisms ranging from the smallest bacteria, to invertebrates, to larger decomposers are all actively eating the wood. Decomposers, and organisms that feed on decomposers, act as a source of food for aquatic organisms such as salmonids. In this manner, large wood supports an entire local ecosystem. The ability of instream wood to increase productivity and food availability within the stream is valuable to coho salmon and steelhead populations.

Large instream wood is a critical factor in development of pools (Keller et al., 1981). Leicester (2005) found that diameter, length and presence of a rootwad were important in determining if large woody debris (LWD) would scour pools and provide valuable structure to the stream. She found that small diameter wood greater than 20 feet in length, or LWD three feet or greater in diameter, was more likely to be structure-forming, and much of this valuable LWD had the rootwad attached (36-56%). This means that when the County or others cut up an instream tree, only the section with the rootwad attached will likely provide valuable LWD. Pools created by instream wood have several benefits to anadromy, including: a step-wise velocity reduction making upstream migration easier and creating slack waters for adults to rest and avoid predation; habitat and escape cover for juveniles; stabilization of spawning gravels at tails of pools; and increased oxygen concentration and food supply. Pool density per stream length is important to fish density, especially in tributary or headwater streams of the San Lorenzo River watershed.

Stable instream wood aggregations can provide shelter from high winter flows that other forms of cover cannot. During storm events or high winter flows, normal cover objects such as boulders, root masses and small woody debris become turbulent zones where small salmonids may be washed away. During the winter, these objects may become scoured or buried more, reducing their value as cover from streamflow. Large wood accumulations are often large enough to provide still water refuges for small salmonids during high flows. Instream wood may also cause the formation of side channels or backwaters, which can provide refugia against extreme winter streamflows (USDA Forest Service, 2002). These refugia are critical in the survival of juvenile salmonids (especially young coho that hatch earlier in the spring than many young steelhead) and the production of smolt sized fish throughout the watershed. Large instream wood modifies channel morphology and processes, creating dynamic aquatic habitat.

Large wood and wood accumulations create and provide habitat for a wide array of aquatic life including anadromous fish. The amount of instream wood has a direct influence upon the number, size and age distribution of fish populations in streams (USDA Forest Service, 1990). The agency found a direct correlation between the amount of wood in a stream and the number of fish found in the stream, as shown in Figure 4.8.

Figure 4.8 Number of coho salmon found in a stream in relation to amount of instream wood.



Source: USDA Forest Service, 1990.

Large instream wood increases the complexity of stream habitat. Some of the best aquatic habitat in the San Lorenzo River watershed is provided by accumulations of large instream wood or rootwads. Figure 4.9 shows fallen redwood trees forming instream wood in Carbonera Creek. Rootwads provide a substantial cover and habitat within a stream. When such habitats are sampled for fish, they contain high densities of steelhead, larger yearling steelhead, as well as non-salmonid species. Large instream wood can provide still-water refuges for small salmonids during high winter flows. Large instream wood harbors insects that can be a food source for juvenile salmonids. Large instream wood also forms resting cover from predators for adult salmonids during their spawning migrations.

Large instream wood acts as scour objects to create fast waters, form pools, and increase depths of pools, as shown in Figures 4.9 and 4.10. Embedded into a streambank, large wood can both protect the bank from erosion, and create undercut banks that are extremely beneficial to fish. One undercut bank in Waterman Gap was created by a large redwood log embedded into the bank, just upstream of a large boulder with an old growth redwood rootwad holding the boulder in place. The streambank was undercut at least three feet and water depth was 2-3 feet in the pool that it had scoured. This was especially deep for a headwater area. This configuration helped to stabilize the bank and created habitat for smolt-sized, yearling steelhead captured and released at this site during population monitoring (Alley, 2005).

Figure 4.9 Large redwood logs forming instream wood.

Alley 2005

Downstream view of wood that was sieved out of the stream channel by large redwood logs in Carbonera Creek

Figure 4.10 Large instream wood creates habitat favorable to native salmonids

Alley 2004

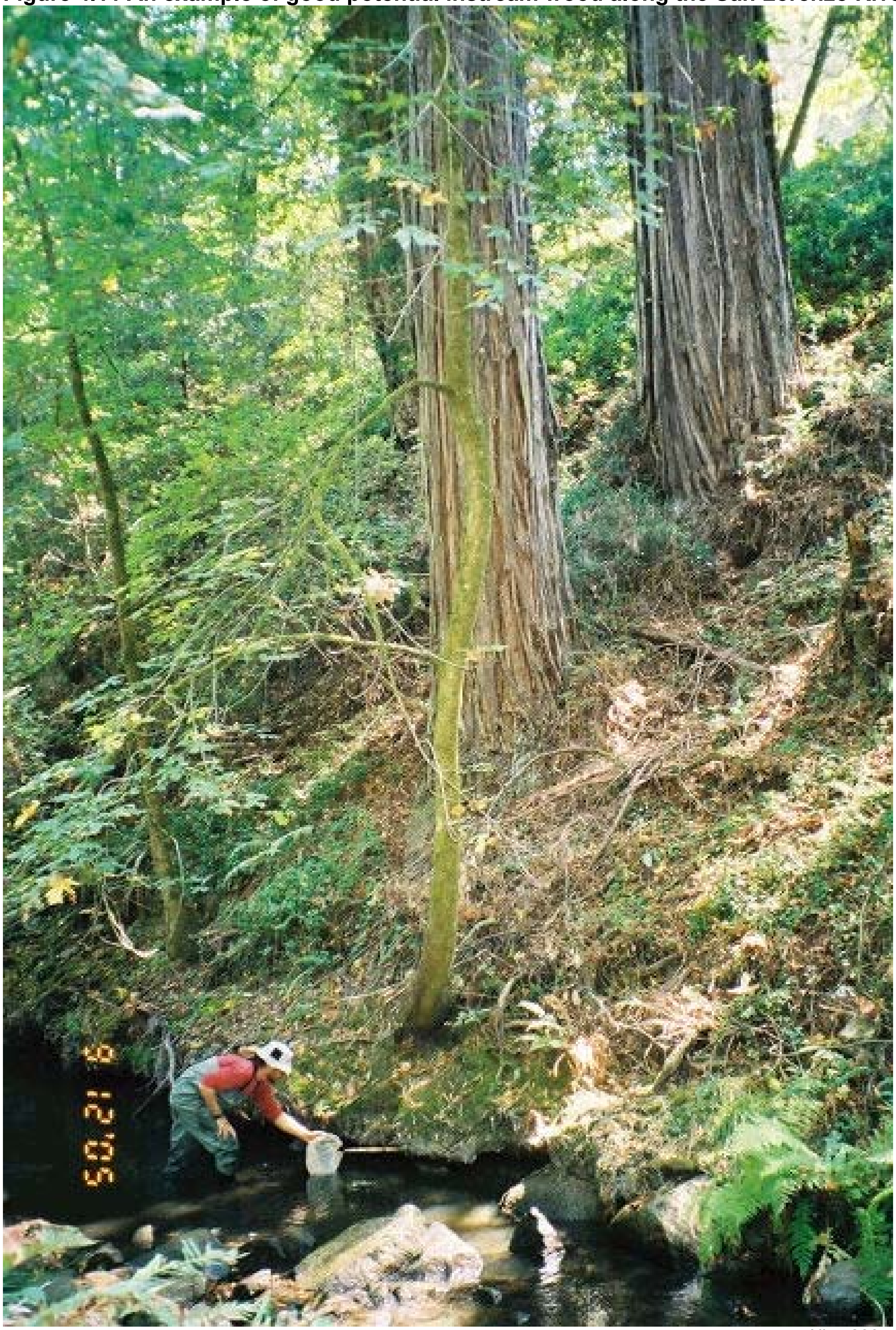
Pool at Waterman Gap, scoured by large, knobby wood embedded in the streambank (right) and large boulder underneath old-growth redwood stump (upper center).

4.4.4 Distribution of large instream wood

Research has shown that many interacting factors influence the distribution, abundance and transport of instream wood throughout a watershed. These factors include climate, slope, geology, forest death, forest growth, bank erosion, mass wasting, stream transport and decay (Keller et al., 1981; Benda and Sias, 2002; Benda et al., 2002). Benda and Sias (2002) identified six processes as key in the abundance and distribution of wood in streams:

- Episodic forest death
- Forest growth
- Chronic mortality
- Bank erosion
- Mass wasting
- Decay
- Stream transport.

Figure 4.11 An example of good potential instream wood along the San Lorenzo River.



Alley 2005

Rare example of old growth redwood still present along the streamside, providing shade, steambank protection, an undercut bank and future large instream wood.

In most of his quantitative studies of instream wood, Benda has found wood storage to be highly variable within streams (Benda et al., 2002). Wood concentrations are highest in small headwater streams and generally decrease downstream (Keller and Swanson, 1979). In old-growth Douglas fir forests in the McKenzie River system of western Oregon, wood concentrations were 48 times higher in a first order tributary than the sixth order mainstem. In the San Lorenzo River watershed, smaller headwater streams are generally steeper and narrower, with a higher potential of input from adjacent slopes, and higher potential for instream wood accumulations. Figure 4.11 shows older redwood trees growing along the San Lorenzo River watershed, providing a potential source of high-quality instream wood.

In small headwater streams, large wood generally remains where it falls, due to lack of sufficient streamflow in tight channels. In mid-sized streams, streamflow can redistribute wood with distinct accumulations that may affect channel form and behavior. In large rivers, wood accumulates around obstructions or in the high water zone on the banks (Keller and Swanson, 1979).

Benda et al. (2002) found diameters of wood to be significantly greater in streams within old-growth forests, compared to streams in second-growth forests. High volumes of stored wood in streams of old-growth forests were primarily due to streamside landsliding (Benda et al., 2002). Another study found recruitment from debris flows to be the single largest source of wood to streams (Benda and Sias, 2002).

Variability of wood distribution and abundance along streams of old-growth redwood forests was related to the frequency of large diameter redwood trees near the channel (Tally, 1980 as cited in Napolitano, 1998). Abundance and distribution of wood within stream networks depend largely upon the mortality rate of the adjacent forest. Chronic mortality, generally higher in second-growth forests than in old-growth forests (Benda and Sias, 2002; Benda et al., 2002), can steadily contribute wood to streams over long periods of time. Stochastic events affecting mortality can cause pulses of wood input to stream systems. Examples of stochastic events are stand-replacing fires, freezes, windstorms, blights, and diseases. Variations in fire frequency affect mortality rates, stand age and age distribution of forests, and thereby the frequency and location of wood input and erosion to streams (Benda et al., 1998).

Bank erosion, generally due to high streamflow storms, causes episodic contributions of instream wood. Rates of erosion depend upon streamflow, location, vegetative density, rainfall intensity, soil type, soil grain size, stability, and reinforcement by roots (Benda and Sias, 2002). Fluvial transport (transport by the stream) depends upon streamflow, channel volume, channel width, slope, obstructions, wood size and wood shape. Pieces that are transported tend to be shorter in length than the channel bankfull width (Benda and Sias, 2002).

The time it takes wood to decay determines the length of time that wood resides within the stream channel. Rates of decay depend upon the species of tree. Instream wood from old-growth redwood logs is very slow to decay, and can remain in the stream for centuries (Keller et al., 1981; Napolitano, 1998; Benda et al., 2002).

Large wood accumulations can span long distances with tightly interlocking pieces of wood, and may persist for decades, until pieces decay or streamflow is high enough to flush the wood downstream (Keller and Swanson, 1979).

4.4.5 Salmonids and other native fishes in the San Lorenzo River watershed

The San Lorenzo River and its estuary are inhabited by at least 25 different species of native fish. These include salmonids and other anadromous fish, which spend part of their lives in the ocean and part in freshwater. The anadromous species of recreational interest are steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). These salmonids live as juveniles in freshwater, spend their major growth and adult stages in the ocean, and return to spawn in their natal freshwater streams where they were originally hatched. For more information on the life cycles of coho and steelhead, refer to Appendix A: Fisheries.

Other native fish living upstream of the lagoon/estuary include anadromous Pacific lamprey (*Lampetra tridentata*), threespine stickleback (*Gasterosteus aculeatus*), speckled dace (*Rhinichthys osculus*), coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*Cottus asper*), California roach (*Hesperoleucus symmetricus*), and Sacramento sucker (*Catostomus occidentalis*).

The San Lorenzo River watershed provides over 80 miles of stream habitat for anadromous salmonids (Ricker and Butler, 1979). Coho salmon and steelhead are two species inhabiting the San Lorenzo River watershed upstream of the lagoon that are listed as threatened or endangered under State or Federal law, and are the only species whose populations have been monitored intensively. However, coho salmon rarely reproduce successfully any longer in the watershed. Juvenile coho salmon were detected in 2005 during fall sampling in Bean Creek, indicating successful spawning, 24 years after their last capture during fall sampling. However, a few stray coho adults, presumably from northern drainages, were captured and released at the Felton diversion dam during the winter of 2004 (14 adults), 2005 (16 adults) and 2006 (2 adults) (Alley, 2008).

4.4.6 Life history of native salmonids

Both steelhead and coho salmon are known as “salmonids” and are in the family Salmonidae and salmon genus, *Oncorhynchus*. Technically, steelhead are salmon; not “trout.” While the life histories of the two species are similar, they differ in timing of spawning, the ability to spawn multiple times or not, time to maturity, and in certain habitat requirements. For more information about the requirements of native salmonids, refer to Appendix A: Fisheries.

Adult, ocean-dwelling steelhead enter coastal streams and spawn over a longer spawning season than coho salmon, and most migrate and spawn later in the rainy season than coho. Coho spawn mostly from late November through February in this region. Steelhead spawn mostly from January through April, but may spawn as early as November and as late as June.

As soon as streamflows are high enough to breach the sandbar at the river mouth, which forms over the summer, adult steelhead and coho may begin their upstream migration. The sandbar is usually open from late November through June or later, depending upon the winter and spring storm patterns. Both coho and steelhead move upstream to spawn primarily after the peak stream discharge of stormflows.

During low flows between storms, passage impediments may delay upstream migration. These impediments include boulder falls or wide, shallow riffles in the San Lorenzo River gorge, or summer dam abutments further up the mainstem. Adults may wait just below these temporary barriers until sufficient stormflow make them passable. Salmonids may have difficulty locating the fish ladder at the Felton diversion dam during intermediate stormflows.

4.4.7 Monitoring of salmonids in the San Lorenzo River

The District has sponsored annual monitoring of salmonids the San Lorenzo River watershed by certified fisheries biologists since 1993. Figure 4.12 depicts these biologists sampling for juvenile steelhead.

Figure 4.12 Biologists measuring and releasing juvenile steelhead

Collins 2007

Biologists measuring and releasing juvenile steelhead during monitoring in the San Lorenzo River at Henry Cowell Park, a project funded by the District.

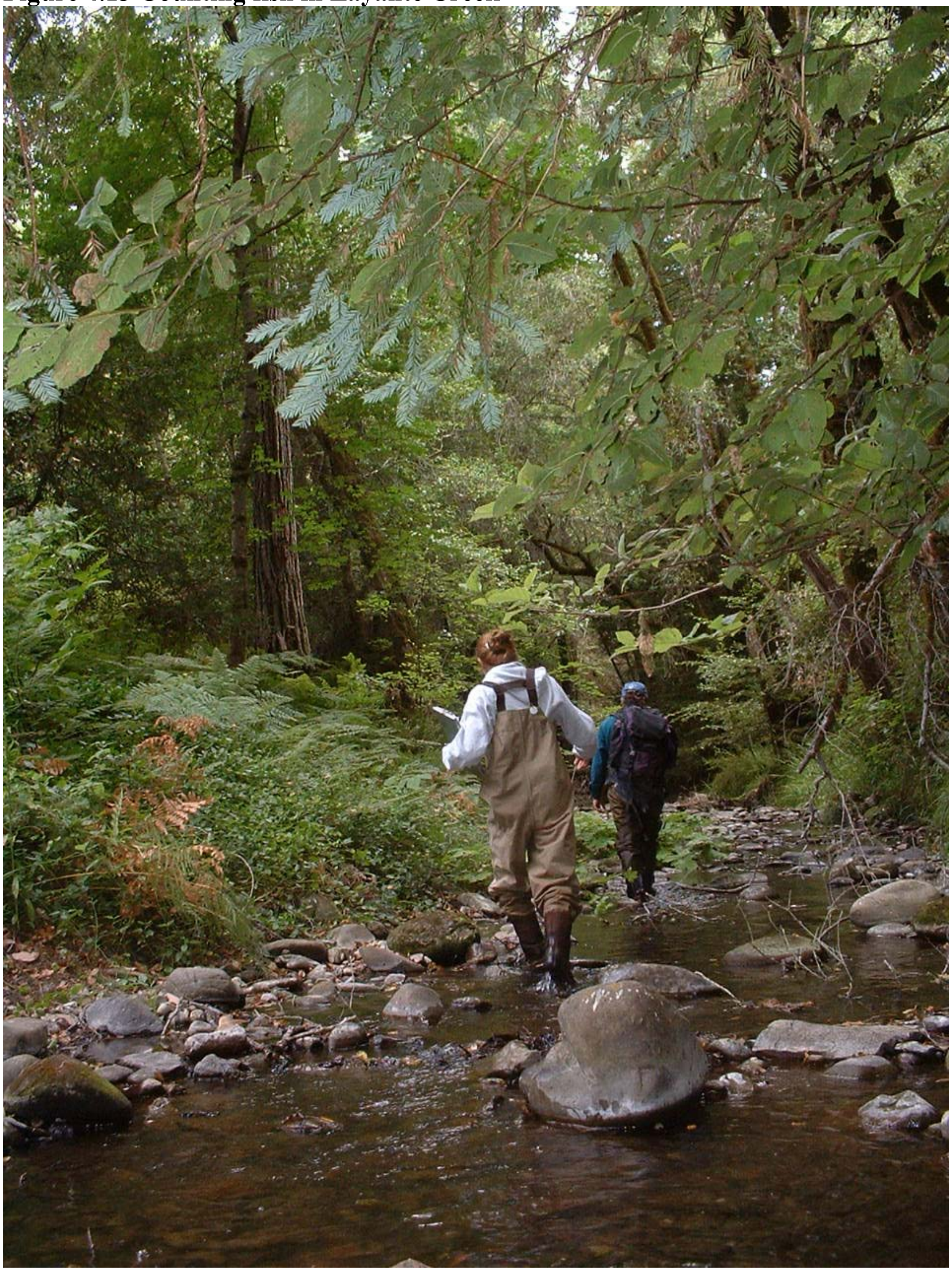
4.4.8 Salmonids on District-owned land

The District's lands and water supply creeks on Ben Lomond Mountain, as depicted in Chapter 1, Figure 1.1, are generally too steep to allow passage of anadromous salmonids, with the exception of Clear Creek. Barriers to fish passage below the District's lands further restrict salmonid access to these areas.

NOAA fisheries biologists surveyed the salmonid populations in the Zayante Creek in the summer 2005 and 2006, after obtaining permission from the District to access portions of the creek that run through District-owned lands. Zayante Creek does not serve as a water source for the District. The survey was part of an ongoing project by NOAA to evaluate the status of salmon and steelhead populations on the Central Coast. The goal of the research project is to provide scientific guidance on how to design and implement a monitoring program in Santa Cruz and Monterey counties, encompassing a systematic, random sampling of streams. Such a monitoring program would enable biologists to evaluate patterns and trends in abundance or distribution over broader geographic areas (i.e., outside of those reaches surveyed) (Spence, 2007). This NOAA monitoring program would supplement other local research and monitoring programs, which are useful in determining trends in abundance or distribution of fish for the specific stream reaches being examined (e.g., Alley, 1993-2007).

Figure 4.13 shows NOAA fisheries biologists documenting fish populations in Zayante Creek on District property.

Figure 4.13 Counting fish in Zayante Creek



Herbert 2007

In summer 2006, NOAA fisheries biologists surveyed 47 randomly selected stream reaches throughout the region, each about 1.0 km in length. The District's Zayante Creek site was one of the reaches sampled. At the District's Zayante Creek site, the biologists visually observed steelhead in most habitats 12 inches deep or greater, as they snorkeled a segment of Zayante Creek upstream of the Mountain Charlie Creek confluence, noting both young-of-the-year and older juveniles. No coho salmon were observed during the survey.

4.4.9 Decline of salmonids on the Central Coast

FishNet 4C is a County-based salmon protection and restoration program that includes the Central California coastal counties of Mendocino, Sonoma, Marin, San Mateo, Santa Cruz and Monterey (Fishery Network of the Central California Coastal Counties, 2007). Following the Endangered Species listings of coho salmon and steelhead trout, County Supervisors from these counties formed FishNet 4C in 1998, to coordinate programs for salmon and fishery restoration.

The focus of the FishNet 4C program is on implementing on-the-ground restoration projects, employing best management practices during maintenance activities, and incorporating aquatic habitat protections into land use regulations and policies.

A UC Berkeley Extension study (Harris and Kocher, 2001) assessed existing county policies and actions throughout the region that may impact salmonid streams. The report identified numerous policy gaps and recommendations for Santa Cruz County, which should be addressed in order to meet FishNet 4C goals.

4.4.10 Decline of salmonids within the San Lorenzo River watershed

Both coho salmon and steelhead were once common and widespread throughout the coastal streams of the Pacific coast. Coho salmon historically occurred in as many as 582 California streams, from the Oregon boarder to their southern limit around the Monterey Bay (Brown et al., 1994). The San Lorenzo River fishery once added significant value both to the county's economy and to the experience of individual anglers. Historically, the two most important anthropogenic impacts on the decline of salmonids in the San Lorenzo River have been identified as sedimentation (i.e., the siltation of rearing pools and spawning beds) and the decrease in summer flows due to pumping and water diversions (County of Santa Cruz, 1979). These and other adverse impacts affecting coho salmon and steelhead in the watershed are discussed further below.

4.4.10.a Decline of coho

The Central California Coast coho salmon forms a separate evolutionarily significant unit (ESU) of the species, extending from Punta Gorda in Northern California to the San Lorenzo River. This means that the San Lorenzo River marks the southern end of the Central California Coast Coho Salmon ESU range. As a result, the challenges this salmon faces are more extreme than those faced by their northern relatives, in terms of elevated stream temperatures and reduced streamflows (NMFS, 2005).

The Central California Coast Coho Salmon ESU was listed under the federal Endangered Species Act as a threatened species in 1996. Accessible reaches of the San Lorenzo River (excluding stream reaches above Newell Creek Dam) were included within the critical habitat designation for the ESU. NMFS (2001) completed a status review of coho populations from the Central California Coast and the California portion of the Southern Oregon/Northern California Coast ESU in response to a petition to protect these populations under the Endangered Species

Act (ESA) (Busby et al., 1996). In 2005, coho were listed as endangered under the federal Endangered Species Act (ESA). Coho salmon south of San Francisco Bay were previously listed as an endangered species by the state of California.

NMFS began the recovery plan for the Central California Coast Coho Salmon ESU in 2005, as required by the federal ESA. Recovery is the process in which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the federal ESA are no longer needed. A variety of actions may be necessary to achieve the goal of recovery, such as the ecological restoration of habitat or implementation of conservation measures with stakeholders (NMFS, 2004).

4.4.10.b Decline of steelhead

NMFS (NOAA Fisheries) adopted a final rule, designating steelhead in the Central California Coast ESU as a federally threatened species, effective October 17, 1997 (NMFS, 1998).

At this time, the designation applies only to naturally spawned populations of anadromous forms of *O. mykiss,* residing below long-term naturally occurring or man-made impassable barriers. The San Lorenzo River is included in critical habitat designated for all accessible reaches, except for stream reaches above Newell Creek Dam. Steelhead south of San Francisco Bay are considered a sensitive species by the state of California.

Loss of steelhead and coho habitat has resulted from dams, water diversions, increased stream water temperatures, stream alterations, sedimentation, excessive scour and other impacts associated with agriculture, logging, mining, urbanization, roads and development. These activities are associated with a dramatic reduction in habitat complexity, including the reduction in large instream wood and an increase in sedimentation (Sanderlock, 1991 as cited in Brown et al., 1994). Napolitano (1998) reports that high quality fish habitat results from complexity and stable conditions.

4.4.10.c Requirements for salmonid rearing habitat

Rearing habitat includes the following characteristics:

- Adequate flows for pool development and to provide fastwater feeding stations for fish
- Escape cover such as undercut banks, rootwads, large instream wood, unembedded cobbles and boulders, surface turbulence, and submerged or overhanging vegetation or debris
- Aquatic and terrestrial insects for food
- Suitable water quality conditions related to water clarity, water temperature, dissolved oxygen concentrations and contaminant levels (Smith, 1982).

Steelhead and coho salmon bury their eggs in gravels. Steelhead larvae live in gravels and cobbles for five to ten weeks from the time the eggs were deposited. The larvae, called alevins, need oxygen rich water flowing through the gravels in order to develop and survive. Alevins also rely on the water flowing through the gravel to remove metabolic wastes. Alevins must swim (emerge) upward through cracks and crevices between gravel particles in the streambed to reach the stream once their egg sacs are absorbed. Gravel clogged with too much fine sediment impedes this effort and increases mortality rate.

Stream dynamics leading to the maintenance of high quality spawning gravel is imperative to population health for steelhead and salmon. Pool depth is also important for all stages of salmonids. Juvenile anadromous fish use spaces under boulders, logs, roots, and undercut banks as escape cover from predation or extreme streamflow. Many other fish species, including the anadromous lamprey, use these same aquatic habitats.

Pools that act as sediment entrapment basins are the first to fill and the last to clear of sediment. Pools are important habitat for anadromous fish, especially in the tributaries and headwater reaches.

Natural processes create aquatic habitats that are critical to salmonids (Spence et al., 1996). Different aquatic habitats are required for different salmonid life stages. For example, graveled-glides are used for adult spawning, fastwater habitat is used for juvenile feeding. Pools provide juvenile cover and feeding areas. Large objects in the channel provide slackwater resting sites for overwintering juveniles and migrating adults.

4.4.10.d Limiting factors for local salmonids

The primary limiting physical factors to fishery productivity in the San Lorenzo River watershed are those that impact spawning access and rearing habitat for juveniles (Ricker and Butler, 1979; Smith, 1982). These limiting factors include:

- Streambed sedimentation with fine sediment
- Reduced stream flow during spawning and rearing
- Shortage of instream wood
- Barriers to adult spawning migration (limits to anadromy)

For a detailed description of limiting factors to salmonids, refer to “Appendix A: Fisheries.”

Streambed sedimentation with fine sediment

Background sedimentation is a natural part of the San Lorenzo River. Sedimentation is greatly increased from upland human activities. Sedimentation affects every salmonid life stage within the freshwater environment. Fine sediment reduces water percolation through spawning gravels, impacting survival of salmonid eggs and emerging fry. Fine sediment impacts juvenile rearing habitat by reducing pool depth, and burying boulders and cobbles that juveniles may hide under.

Loss of cracks and crevices between cobbles in riffles decreases aquatic insect habitat and reduces food availability for salmonids. Water turbidity associated with sedimentation also impacts salmonid feeding capability. Salmonids are visual feeders, and need clear water to see their drifting prey. The longer the stream remains turbid after a storm in spring (the most important feeding season for juveniles in small coastal watersheds), the less feeding time available to juvenile salmonids. Thus, turbidity can greatly reduce growth rate.

Aquatic insects inhabit primarily the cracks and crevices between larger cobbles and boulders in fastwater habitat that includes riffles, step-runs and runs. The less fine sediment present in these habitats, the greater the spatial heterogeneity and insect habitat that exists. Thus, if fastwater habitat becomes filled in with fine sediment, burying (embedding) cobbles and boulders, then insect production is reduced, as is food for salmonids.

Sedimentation can affect adult upstream migration by making pools shallower. In order to migrate upstream past instream barriers, salmonids need adequate pool depth below the barrier in order to jump over it. Adult steelhead generally require these approach pools to be at least as deep (some say twice as deep) as the barrier is high, for a successful jump.

Reduced streamflow during spawning and rearing

Winter streamflow, as determined by storm runoff, deepens stream channels making them more easily passable to spawning adult salmonids. Insufficient stormflow may delay or even prevent passage over partial migration barriers, thus limiting access to valuable spawning habitat in tributary streams. Streamflow as a limiting factor is the primary element that defines total available spawning and rearing habitat for salmonids. Streamflow determines drift rate of aquatic insects and, therefore, food supply for salmonids. Less streamflow causes slower water velocities and reduced insect drift rate.

Shortage of instream wood

Benefits of instream wood are discussed at the beginning of this section. The loss of instream wood in the San Lorenzo River watershed is the result of logging, development, and logjam removal policies and practices.

Barriers to adult spawning migration

Barriers to adult spawning migration prevent fish from migrating to and from their natal streams. Barriers range from complete obstructions during all streamflows, to partial impediments, such as riffles that become too shallow to allow fish passage during low streamflow. These barriers may be natural or artificial. Natural passage barriers include waterfalls, bedrock chutes, logjams, large boulder fields, steep riffles, shallow riffles, and bedrock ledges. Natural barriers may be completely removed or altered by storms to allow passage.

Artificial passage barriers include unladdered dams for water storage reservoirs, water diversion dams, summer flashboard dams, weirs, bridge abutments with concrete sills, perched culverts, and instream road crossings.

For a more complete description of limiting factors to salmonids, refer to Appendix A, Fisheries.

4.4.11 Reptiles and amphibians

The following reptiles and amphibians may be found on District owned lands.

The *California red-legged frog*, pictured in Figure 4.14, is a State Species of Special Concern and is federally listed as threatened. It inhabits quiet pools along streams, in marshes, and ponds. Red-legged frogs are closely tied to aquatic environments, adults favoring perennial streams with deeper pools that have considerable escape cover from instream wood or overhanging riparian vegetation in summer. Inhabited pools may vary in depth, with cover being the most important factor (Alley, 2008). Young metamorphs are typically found in shallow, fastwater habitat. Breeding occurs in off-channel ponds and freshwater portions of wetland marshes. The loss of these breeding areas and the introduction of bullfrogs have been key to the disappearance of red-legged frogs in many areas. Recent studies have shown that red-legged frogs are capable of moving distances of up to 2 miles (Bulger, 1999 as cited in Swanson Hydrology & Geomorphology, 2001). The red-legged frog occurs in the Coast Ranges along the entire length of the state.

Within the San Lorenzo River watershed, red-legged frogs have been observed in the lower portion of Laguna Creek from the mouth to Smith Grade and on Mt. Charlie Creek, tributary to Zayante Creek (Berry, as cited in Alley, 2008), and at Fall Creek in Felton (Froke, 2004).

Figure 4.14. The California red-legged frog

Alley 1992

A California red-legged frog in the headwaters of Baldwin Creek, tributary to the San Lorenzo River.

The *foothill yellow-legged frog* is a State species of special concern. It is found in or near rocky streams in a variety of habitats, including mixed conifer, mixed chaparral, and wet meadows (Zeiner et al., 1988). It is rarely found far from perennial or intermittent streams (Stebbins, 1985). Larger adults forage next to deeper pools with abundant escape cover. Small foothill yellow-legged frogs are typically found along sunny, exposed cobble bars near shallow stream habitat that they may quickly retreat into to avoid predators. The young prefer sites with riffles and at least cobble-sized prefer sites with riffles and at least cobblesized substrates (Hayes and Jennings, 1988). A stronghold for foothill yellow-legged frogs is Soquel Creek. They may occur in Laguna or Zayante Creeks (Swanson Hydrology & Geomorphology, 2001).

The *southwestern pond turtle* is a Federal and State Species of Special Concern. This aquatic turtle inhabits ponds, lakes, streams, marshes, and other permanent waters located in woodland, grassland, and open forests below 6,000 ft (Stebbins, 1985). Pond turtles can often be seen basking in the sun on partially submerged logs, rocks, mats of floating vegetation or mud banks. During cold weather, they hibernate upland away from the stream in soft soils where they also may bury their eggs at other times. Nesting activity may occur in flat, sunny upland areas, such as grassy meadows and chaparral as much as 500 meters from water (Rathbun et al. 1993). Pond turtles have been observed at Loch Lomond Reservoir (Swanson Hydrology & Geomorphology, 2001).

California horned lizard is a California Species of Special Concern. This reptile is typically found in riparian habitat (e.g., cobble areas along rivers), chaparral habitat, annual grasslands, and alkali flats. Habitat loss is believed to be the primary cause for decline in this species numbers (Jennings and Hayes, 1994 as cited in Swanson Hydrology & Geomorphology, 2001).

4.5 Ecosystem functions and natural services

This section provides an overview of ecosystem functions and natural services provided by late successional forests, the riparian zone, aquatic habitat, and sandhills communities of the region, in the San Lorenzo River watershed, and on District lands. These ecosystems are most important for the District's water supply.

The District has not identified, mapped, and analyzed species indicating watershed ecosystem health, with surveys, sensitivities to potential management actions and climate change; nor has the District used the California Wildlife Habitat Relationships System to perform a habitat analysis for any wildlife indicator species.

Ecosystem functions include the fundamental natural processes upon which life depends.

To function properly, ecosystems depend on interactions between a number of biogeochemical cycles, including the hydrologic or water cycle, nutrient cycles, the carbon cycle, the flow of energy, ecological community dynamics, and succession. All of these cycles may all be modified by human actions. Refer to Chapter 3, Hydrology, Geomorphology, and Water Quality for additional information on the hydrologic cycle. Refer to Chapter 7, Local Climate Change Assessment for additional information about the carbon cycle.

When ecosystems function properly, they produce natural services that are useful to people. Such natural services include:

- Provision of clean water and air
- Flood control
- Pollination of crops
- Mitigation of environmental hazards
- Pest and disease control
- Carbon sequestration
- Aesthetic, cultural and ethical values associated with biodiversity.

Accounting for these natural services is an increasingly popular area in the field of economics. When natural services are assigned an economic value, protecting ecosystem function tends to make more economic sense. For example, mature forests provide water filtration services that serve to offset water treatment costs. The value of a forest's natural filtration services likely exceeds the potential timber value of the forest. However, unless the forest's water filtration services can be given a monetary value, the forest is likely managed for its timber, which is priced by the board foot.

The District's 1985 watershed protection plan stated the importance of a healthy watershed:

> The attractive natural environment in this area is the major selling point for the watershed's tourist and real estate industries. Vegetation and wildlife are not merely luxuries; they provide a significant contribution to the economy of the area" (San Lorenzo Valley Water District, 1985).

4.5.1 Ecosystem functions of old-growth and late successional forests

As cited by Singer in Swanson Hydrology & Geomorphology (2001), forest ecologist Jerry Franklin (1981) identified four major structural attributes of old-growth forests: live old trees, large snags, large down logs on land, and large down logs in streams. Additional important elements were added by Franklin and Spies (1991A) and included a multi-storied canopy, smaller understory trees, canopy gaps, and a patchy understory.

Forests containing either old-growth or mature second-growth stands are known as late successional forests. Kohm, Franklin et. al., 1997 attribute the following ecosystem functions to late successional forests, which include old-growth and mature second-growth:

- Buffering of microclimate during seasonal climatic extremes
- Producing food for consumer organisms
- Storing carbon which can act as a buffer to large scale climate change
- Retaining high amounts of nutrients and water, including a high capacity for intercepting fog and rain (particularly by the epiphytic lichens and mosses)
- Providing sources of arthropod predators and organisms beneficial to other ecosystems or successional stages
- Maintaining low soil erosion potential

4.5.1.a Ecosystem functions of forest soils

Small streams and headwaters within old growth forests receive most of their nutrients from leaf litter and wood. Forest ecologists have found that nutrient capture and recycling are essential to the long term stability and health of ecosystems. When nutrient inputs no longer balance nutrient loss (such as following disturbance or climate change), nutrients become limited and vegetation changes, initially as increased mortality of the most sensitive species, followed by reduced stature of dominant vegetation (Kohm, Franklin et al., 1997).

Surface soils in old-growth redwood forests typically have a thick litter layer and high organic content, so that rainfall infiltration is high and runoff is low. These qualities reduce erosion and sedimentation (Spence et al., 1996). Old-growth forests store water and release it slowly over time, enhancing stream flow in spring and summer, and reducing surface runoff during winter storms. These filtration and water storage characteristics provide strong rationale for water utilities to manage forested watershed lands toward old-growth conditions.

Because of a thick litter layer and a favorable climate, old-growth redwood forests contain extremely high numbers of the soil invertebrates, fungi, and, to a lesser degree, bacteria. Their role in decomposition of organic litter is a crucial one, since it recycles nutrients needed by the growing trees. Some of the invertebrate species are the centipedes, millipedes, and sowbugs visible to the naked eye, but most are microscopic orbatid mites (Moldenke and Lattin 1990).

The multitude of microscopic soil organisms present in these soils comprise the greatest area of biodiversity in old-growth forests. One square meter of forest soil contains 200,000 orbatid mites within about 75 different species. When other soil invertebrates are included (predatory mites, beetles, springtails, spiders, etc.), that same square meter of soil will have been found to contain 200 – 250 different species of soil invertebrates (Moldenke 1990, Moldenke and Lattin 1990). If one considers the number of microscopic soil invertebrates present, then the Pacific Coastal Temperate Rainforests, including redwood forests, support more biodiversity than tropical rainforests (Moldenke 1990, Moldenke and Lattin 1990).

Fungi also play several important ecological roles in forest soils. Much of the organic material produced in nature is broken down by bacteria, but not so in the forest. Forest debris, twigs, branches, and down logs, is composed of woody tissue containing lignin. Lignin cannot be broken down by bacteria. Only fungi can break down lignin and complete the decay process in woody debris. Consequently forest soils are dominated by fungi, not bacteria. In one gram of healthy forest soil there may be up to 20 miles of thread-like fungal filaments called hyphae (Tugel and Lewandowski 1999)). So unlike other ecosystems where bacteria are the key decomposers, in the forest fungi control the process of decay and decomposition.

But fungi in forest soil don't just associate with dead wood. They are also key players in allowing, supporting, or enhancing the growth of forest trees. A particular type of fungi does this through a symbiotic relationship with the roots of trees. These fungi are called mycorrhizal fungi. They act as an extension of the root system into the soil, providing water and nutrients to the tree in return for sugars (produced by photosynthesis) passed from the tree to the fungi. Mycorrhizal fungi also protect the tree from root pathogens and a number of adverse soil conditions. Studies have shown that mycorrhizal fungi are essential for normal tree growth (Perry 1994).

Threats to beneficial forest soil biota include: (1) the use of pesticides or herbicides, (2) timber harvest activities that incorporate soil disturbance or compaction, (3) catastrophic wildfire (i.e., a fire that is unusually hot or of long duration), and (4) soil erosion (U.S. NRCS 2004).

In redwood forests, vascular plant epiphtyes grow in great abundance only on old-growth redwood trees located within 10 kilometers of the ocean (Sillett and Bailey, 2003). Locally, the greatest epiphyte growth occurs on Douglas-fir trees, rather than redwood (Singer, 2008). The most abundant vascular plant epiphyte on redwood is the leather fern (*Polypodium scouleri*) (Sillett and Bailey, 2003). It is found in large aggregations (mats) on branches and trunks high in the redwood canopy. Of 27 redwoods sampled along the coast of Del Norte and Humboldt counties, 13 had fern mats of leather fern. Other ferns that grow as epiphytes on redwoods include the licorice fern (*Polypodium glycyrrhiza*), sword fern (*Polystichum munitum*) and lady fern (*Athyrium filix-femina*) (Sillett and Van Pelt, 2000; Sillett and Bailey, 2003).

Other epiphytes found in old-growth canopies, and typically found in greater abundance in the Santa Cruz Mountains, are mosses and lichens. Mosses and lichens provide habitat for invertebrates, retain nutrients and moisture for forest trees, and organic material for soil. Nitrogen-fixing canopy lichens, like the Lungwort (*Lobaria pumonaria*), fall or are blown off of trees and provide an important nitrogen source for forest soils. During the winter fragments of this large cabbage leaf-like lichen are an important browse for deer in old-growth stands. They are generally associated with late successional forest ecosystems (100+ years).

4.5.1.b Ecosystem functions of snags

An old-growth forest contains many snags and large downed logs in various stages of decay, which are found both on the forest floor and in streams. Both snags and downed logs play an important role in the forest ecosystem.

A snag is a dead or partly dead tree at least four inches in diameter at breast height (dbh) and at least six feet tall (San Lorenzo Valley Water District, 1985). Large-diameter snags provide the greatest variety of nesting habitat and stand longer than smaller snags (Bull et al., 1997). Large dead snags in an old-growth forest can stand for over 200 years. In the redwood forests of the Santa Cruz Mountains, almost all snags are provided by Douglas-fir, an important associate of redwood in redwood forests. Redwoods are so long-lived that they may never die from old-age, whereas Douglas-firs in the Santa Cruz Mountains seldom, if ever, live beyond 400 years. Douglas-firs are also susceptible to death from fire, and redwood generally is not. So the recruitment of large snags and large down logs in a redwood stand is largely dependent on a component of Douglas-fir trees in the stand (Singer, 2008)..

The role of snag-dependent species has been recognized in the regulation of insect populations (San Lorenzo Valley Water District, 1985). Most birds and many mammals that depend on snags are insectivorous, and represent a major portion of the insectivorous animals of a forest. In combination with other disturbances, forest insect outbreaks can pose a serious threat to forest health. In many instances, birds have reduced outbreaks of forest insects (San Lorenzo Valley Water District, 1985). Intact populations of all trophic levels help to minimize outbreaks of "pest" species. Bats, birds, and other insectivorous animals depend upon snags for both food sources and locations for roosting or nesting to support their populations. Leaving snags intact can minimize the impacts of pest species.

The role of snags within a forest is often overlooked. Snags are commonly removed during timber operations, for public safety, to reduce fire hazard, or to lessen the risk of instream log jams. To provide a continuous supply of snag habitat, a certain number of green trees, generally Douglas-firs, should be designated to eventually become snags. Snags can also be created artificially, by girdling or other means, in managed forests (Bull et al., 1997). However, managed forests may never produce the large snags that are essential for pileated woodpeckers. Pileated woodpeckers are a keystone species in that only they can create the large cavities needed for roosting, denning, or nesting by many other forest birds and mammals (Bull and Jackson 1995). Information relating to snags can be input into models to determine the number of green trees necessary to provide ample snag habitat in a managed forest (Bull et al., 1997). Information would include fall rate of standing snags, snag density, live stem density and mortality rate.

4.5.1.c Ecosystem functions of downed logs

A log is defined as a tree, branch or top with large end diameter of at least 6 inches and/or a length of eight or more feet (Bull et al., 1997). Downed logs play a critical ecological role in forests. Logs on the forest floor, especially large logs, serve as reservoirs for water and nutrients. They are sites for bacterial nitrogen fixation, fungal and other decomposers, refuge for invertebrates, small vertebrates, mycorrhizal fungi, and other organisms during fire. They also serve as seed banks and wildlife habitat. Downed logs act to stabilize slopes and prevent erosion.

Decaying logs store large volumes of water, which can be used by other organisms throughout the year. They absorb significant quantities of water early in the decomposition process (Maser et al., 1979). Holding water throughout the year benefits other plants and animals and maintains a higher moisture level than otherwise available within the forest ecosystem. Combined increases in moisture and nutrients in downed logs make them an excellent site for plant propagation. Many animals store seeds in logs, which become seed banks for forest regeneration. Seeds germinate and grow rapidly, due to increased availability of water and nutrients, and shelter provided by the structure of the log.

Logs are classified by their level of decay. Table 4.6 describes the characteristics of five decay classes, with Class 1 logs showing the lowest level of decay. Each class provides different habitat qualities to wildlife. Rates of decay depend upon the species of tree, surrounding habitat, external forces (such as by windthrow, other trees falling or damage by bears), climate, slope, moisture, and number of decomposers in the log.

Class 3 and class 4 logs are important in the colonization of mycorrhizal fungi, which are essential for the healthy growth of live trees. A symbiotic relationship is formed between roots of the fungi and the roots of vascular plants (Maser et al., 1979). Mycorrhizal translates literally as *fungus-root* and defines the common association between specialized soil fungi and the fine roots of nearly all forest plants. Mycorrhizal associations represent one of the more widespread forms of natural symbioses in terrestrial ecosystems. These symbiotic relationships have evolved over the millennia such that each partner depends on the other for survival (Kohm, Franklin et al. 1997). Mycorrhizal associations are necessary for the survival of many trees including pines and Douglas fir (Maser et al., 1979).

Downed logs help to regenerate forests, and the presence of large old snags and downed logs are key characteristics of old growth forests. It is important for land managers to conserve and enhance log recruitment.

Table 4.6 Guide to determining decay class of downed logs in a forest.

Decay Class	Structural Integrity	Texture of Rotten Portions	Color of Wood	Invading Roots	Branches and Twigs
1	Sound, freshly fallen, intact logs	Intact, no rot; conks of stem decay absent	Original color	Absent	If branches are present, fine twigs are still attached and have tight bark
2	Sound	Mostly intact; sapwood partly soft (starting to decay) but can't be pulled apart by hand	Original color	Absent	If branches are present, many fine twigs are gone and remaining fine twigs have peeling bark
3	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Reddish-brown or original color	Sapwood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Through-out	Branch stubs pull out
5	None, piece no longer maintains its shape, it spreads out on ground	Soft; powdery when dry	Red-brown to dark brown	Through-out	Branch stubs and pitch pockets have usually rotted down

Source: Gibbons et al., 2004.

4.5.2 Ecosystem functions of the riparian zone

The *riparian zone* is the area that serves as the interface between the stream or lake and the surrounding upland plant communities. Because of the presence of water, nutrient-rich sediments and organic matter, riparian zones are often characterized by high plant species diversity. Riparian zones also serve as movement corridors for wildlife.

The term *riparian zone* is defined generally in different ways and from different perspectives in scientific literature (Alley et al. 2004). This document uses the definition after Gregory et al. (1991), who defined a riparian zone functionally as a "three-dimensional zone of interaction between terrestrial and aquatic ecosystems." These scientists proposed a conceptual model of riparian zones that integrated research findings from different fields to include geomorphic processes, plant succession, and attributes of stream ecosystems (Herbert, 2004). Ehlers and de Guzman (2002) expanded on Gregory's functional definition by emphasizing gradients within riparian areas:

> Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines.

4.5.2.a Nutrient distribution and flooding

According to Gregory (1988), "If management agencies adopt perspectives of riparian zones that do not address critical ecosystem processes, the integrity of riparian resources cannot be insured."

Disturbance in the form of flooding is important in transporting particulate and dissolved organic matter, and nutrients. Flooding is also serves to export organic material from forests to adjoining ecosystems and their inhabitants. When streams overflow, a large surface area of litter and detritus is exposed to the water, often for a long time. During this time, significant leaching and fragmentation occur, and both dissolved and particulate organic materials are removed from the floodplain (Taylor et al., 1990).

Large floods move great quantities of wood downstream and onto the flood plain. Low frequency, high magnitude floods add much material to streams. Physical abrasion is the most powerful mechanism for removing stable pieces of wood from streams and rivers. Sand and gravel carried at flood velocities abrade large pieces of wood. Abrasion is greater in high gradient or sediment-rich streams than in gentle, spring-fed or low-gradient streams and rivers (Sedell, et al., 1998).

Spence et al. (1996) describe the functions and benefits of riparian corridors:

> Riparian and floodplain areas are the critical interface between terrestrial and aquatic ecosystems, serving to filter, retain, and process materials in transit from uplands to streams. Riparian vegetation plays a major role in providing shade to streams and overhanging cover used by salmonids. Streamside vegetation stabilizes stream banks by providing root mass to maintain bank integrity, by producing hydraulic roughness to slow water velocities, and by promoting bank building through retention of sediments. Riparian vegetation also provides much of the organic litter required to support biotic activity within the stream as well as the large woody debris needed to create physical structure, develop pool-riffle characteristics, retain gravels and organic litter, provide substrate for aquatic invertebrates, moderate flood disturbances, and provide refugia for organisms during floods. Large woody debris performs important functions in streams, increasing channel complexity, creating hydraulic heterogeneity, and providing cover for fish. Large wood also provides critical habitat heterogeneity and cover in lakes, estuaries, and the ocean. In addition to the aquatic functions that riparian areas perform, they typically provide habitat and create unique microclimates important to a majority of the wildlife occupying the watershed.

NOAA Fisheries (2000) recognized that human activities may impact properly functioning conditions for federally protected species, such as steelhead. According to NOAA Fisheries (2000):

> The existence of native vegetation along stream corridors is a condition that can support essential habitat processes such as temperature control, bank stability, stream complexity over time, the filtering of pollutants, or contributions of large logs and other woody debris to a stream.

4.5.2.b Hydrologic function

Riparian zones buffer against increases in sediment input, and regulate sediment transport. The riparian zone buffers and modulates extreme flood streamflows.

Healthy riparian zones protect streambanks from being damaged by objects transported during extreme flood events. Root systems of the riparian corridor armor stream banks against erosion, even when roots are completely exposed. Stems, branches and exposed roots moderate current velocity by increasing hydraulic roughness (Spence et al., 1996). Streambanks with a five-centimeter thick root mat were observed to retard erosion up to 20,000 times more effectively than streambanks lacking vegetation (Smith, 1976 as cited in Keller and Swanson, 1979). Keller and Swanson (1979) found that root systems of riparian trees protect a length of stream bank approximately five times the diameter of the tree. Streambanks protected by root networks of riparian trees often create undercut banks, another habitat highly desirable for anadromous fish. Undercut trees may eventually fall into the stream, supplying large instream wood.

Average channel width and slope are affected by riparian vegetation density (Keller and Swanson, 1979). Tree-lined channels tend to be narrower and steeper than alluvial channels with fewer trees, even though they transport the same amount of water and sediment (Maddock, 1972 as cited in Keller and Swanson, 1979). The steeper narrower channels are able to move more sediment along, compared to wider, flatter, channels that aggrade and fill with sediment. Therefore, healthy riparian corridors can help to reduce sedimentation of channels. The increased input of large instream wood from healthy riparian zones also increases potential scour objects and sediment regulation functions. In larger channels, the riparian corridor buffers flood events and settles out sediments, which fertilize the alluvial riparian zone.

4.5.2.c Water quality enhancement

Healthy riparian ecosystems improve water quality by reducing nitrates and bacterial concentrations. Riparian vegetation regulates heat gained and lost from the sun and air or wind. Temperatures in the riparian zone tend to be cooler during the day and warmer during the night than exposed areas (Spence et al., 1996). Greater convective exchange occurs when temperatures across the air / water gradient are the most extreme (Spence et al., 1996). Riparian vegetation creates a shaded microclimate of relatively high humidity, moderate temperatures, and low wind speed. These conditions tend to reduce both convective and evaporative energy exchange between the air and the water, by minimizing temperature and vapor-pressure gradients (Spence et al., 1996). In this way, riparian corridors moderate both extreme air and water temperature changes. The removal of riparian vegetation increases maximum water temperatures and increase daily temperature fluctuations in smaller streams of the Pacific Northwest (Spence et al., 1996).

4.5.2.d The riparian zone in the San Lorenzo River watershed

Protected areas such as Henry Cowell State Park provide insight into the condition of pre-settlement riparian areas. The riparian zone was much wider historically, and there were large numbers of old growth redwood trees near stream banks.

At Henry Cowell State Park, frequent flooding inundates the entire flat area from the railroad tracks to Highway 9. As a result of this flooding, the soil is rich, fine and deep. Riparian vegetation has adapted to conditions such as these. Riparian woodland plant communities in the San Lorenzo River watershed provide shade, contribute nutrients to the waterway from leaves, contribute large wood, encourage percolation of rain, and resist sediment flow and overland runoff to the waterway on steep terrain. Riparian zones of the San Lorenzo River watershed have the highest breeding bird density of all habitat types in the area (Camp, Dresser & McKee, 1996).

Locally, the Santa Cruz County Environmental Planning Department defines the riparian corridor from a functional perspective:

> The riparian corridor is the area adjacent to the stream that supports a plant and animal community adapted to flooding or wet conditions. Willows, alders, and cottonwoods are common riparian tree species. Redwood and Douglas fir often inhabit the riparian corridor, particularly in the upper reaches of the watersheds. All of these tree species contribute to bank stability, shade, undercut banks, and woody material within the stream.

However, the county uses prescribed distances from waterbodies to delineate the size of riparian corridors:

- Lands extending 50 feet (measured horizontally) out from each side of a perennial stream. Distance is measured from the mean rainy season (bankfull) flowline.
- Lands extending 30 feet (measured horizontally) out from each side of an intermittent stream. Distance is measured from the mean rainy season (bankfull) flowline.
- Lands extending 100 feet (measured horizontally) out from each side of a lake, wetland, estuary, lagoon or natural body of standing water.
- Lands within an arroyo located within the Urban Services Line or Rural Services Line.
- Lands containing riparian woodland (cottonwood, sycamore, alder, box elder, etc.).

(County of Santa Cruz, 2003).

While set distances provide uniformity and predictability from a regulatory standpoint, these prescriptions are not based on biological or ecological relationships at any one location, so the extent of riparian vegetation will vary, depending on local conditions.

(Alley et al., 2004b) describes the variation in size and locations of riparian zones:

> Depending on the configuration of the valley where the riparian corridor occurs, riparian corridor width can range from a narrow strip along the bottom of a canyon (10s of feet wide), to wide swaths of dense vegetation where the canyon opens up into a wide valley floor (100s of feet wide). The function of riparian corridors also differs by location. In the case of a narrow canyon, the roots of riparian vegetation stabilize stream banks, provide scour objects that improve fish habitat, reduce direct sunlight

> and keep water temperatures cool, and provide wood to the channel that act as grade control and escape cover elements. In addition to stabilizing stream banks and providing for improved habitat conditions, riparian corridors on wide valley floors reduce water velocities during flooding events and filter out fine sediment, resulting in improved water quality.

Healthy riparian zones increase native fish populations, to improve sport and commercial fisheries. Benefits of an intact riparian corridor were explained in the Santa Cruz County General Plan (County of Santa Cruz, 1984):

> The riparian corridors adjoining watercourses protect fisheries resources by maintaining low water temperature through shading, providing cover and nutrients, and by trapping sediment before it can reach the watercourse. The roots of this vegetation provide soil strength and prevent or reduce streambank erosion, thereby protecting fisheries resources as well as bridges, roads, and structures which would otherwise be endangered by high stream flows.

The Soquel Creek Storm Damage Recovery Plan, prepared by the Soil Conservation Service after the flood event of 1982, identified an additional important benefit provided by riparian vegetation. It reported that during high stream flows, riparian woodlands filter many logs and other woody debris out of the stream. Contrary to a commonly held belief, the report stated that riparian woodlands trap more woody debris during high flows than they contribute, and reduce the potential for damaging log jams downstream (as cited in San Lorenzo Valley Water District, 1985).

4.6 Human impacts to biotic resources

This section discusses the general problem of human disturbance to native plant communities, wildlife and fisheries habitats, and ecosystem function. It then discusses specific impacts within the San Lorenzo River watershed, and how they impact local biotic resources.

Disturbance may disrupt ecosystem functions in ways that impair the natural services provided by healthy ecosystems, such as provision of clean water. Watershed disturbance may be human induced, or from natural causes. Watershed disturbances may be chronic or acute and may lead to chronic or acute biological responses. Impacts may combine and increase over time, creating cumulative watershed impacts.

Unlike natural disturbances, human induced disturbances are not patchy. Human induced disturbances fragment habitat and ecological communities at a scale in size or time that overwhelms their resiliency. Habitat fragmentation is a serious threat to diversity and species persistence. Landscape scale alteration permanently alters the landscape and degrades ecosystem functions. Potential biodiversity and abundance is reduced due to the reduction in diverse habitats and niches. Habitat loss through conversion to other land uses is the major cause of species endangerment (Jones & Stokes, 1987).

Since the 1800s, the San Lorenzo River watershed has been altered by human land use practices, water diversions, and water use. This section describes these practices and their impacts to plant communities, and wildlife habitats.

4.6.1 Development

Development, which includes housing, roads, and landscaping, has reduced and degraded plant communities and wildlife habitat. While much of the San Lorenzo River watershed remains in open space, development has severely fragmented the landscape. Roads have created miles of linear swaths through viable habitat. Some wildlife species, including the mountain lion, bobcat, and golden eagle, are very sensitive to human disturbance. Some species require large areas, 100 acres or more, of undisturbed habitat (San Lorenzo Valley Water District, 1985).

Development of sandhills habitat increases the area of impermeable surfaces (e.g., roofs, roads), results in increased run off directly to streams, and thus, reduced percolation into the aquifer. Though the District owns a large tract of sandhills habitat, which it manages for its value to the aquifer, land use on private property containing sandhills habitat has the ability to significantly impact the aquifer as well.

Many riparian corridors are now developed with houses and roads. Riparian ecosystems have been removed, altered or destroyed at an alarming rate throughout the state (Jones and Stokes, 1987; California Riparian Habitat Conservation Program, 2003). In the past 150 years, the state of California has lost over 89% of riparian ecosystems (Jones and Stokes, 1987; Birdlife International, 2003). Losses of riparian ecosystems have been primarily due to agriculture, logging and development. Within the San Lorenzo River watershed, the primary causes of riparian habitat loss have been logging, development, roads, and invasive exotic species.

According to the San Lorenzo River Watershed Management Plan (County of Santa Cruz, 1979) a typical private property of the San Lorenzo River watershed, including structure, yard and driveway, creates about one half acre of disturbed area. Light pollution, noise pollution, and impacts from pets may expand this area of disturbance. While the rights of property ownership are of great political importance from the local to national scale, these rights must be balanced with responsibilities, to ensure that individual activities do not adversely affect resources that belong to all citizens (Spence et al., 1996).

4.6.2 Roads

Roads impair hydrologic function, fragment habitats, and are sources of pollution. Trombulak and Frissell (2000; cited by Herbert, 2004) summarized the ecological effects of roads of all types on terrestrial and aquatic communities, finding:

> Not all species and ecosystems are equally affected by roads, but overall the presence of roads is highly correlated with changes in species composition, population sizes, and hydrologic and geomorphic processes that shape aquatic and riparian systems.

These studies used roads as “the best available general proxy of cumulative effects associated with land use and human access” (Trombulak and Frissell, 2000 as cited by Herbert, 2004).

The National Marine Fisheries Service (NMFS, 1996 as cited by Herbert, 2004) used road density as an indicator of watershed condition in formulating guidelines for salmon restoration on the Pacific coast. NMFS designated road densities greater than 3 miles per square mile of watershed, as an indication that the watershed is “not properly functioning.” Road densities have been found to be negatively correlated with fish stocks (Lee et al. 1997, as cited by Herbert, 2004).

Cars pollute the air and leave petrochemical residues on the road surface, which washed into streams as urban runoff. Cars create light and sound pollution. Litter thrown from cars increases trash and can attract animals, increasing the risk of road kill. Remote rural roads facilitate illegal dumping of trash and household appliances. Trash dumped down steep ravines from remote roads often finds its way into streams. Fires can be started in remote areas by people carelessly tossing cigarettes or matches out car windows.

Roads are vectors of distribution for exotic plant species. Road corridors are often lined with non-native plants, which then proliferate throughout the watershed.

Most of the main roads in the San Lorenzo River watershed follow the stream channel, altering both physical and biological characteristics of riparian habitat. Streams have been straightened in some areas to accommodate the roadbed.

4.6.3 Logging

Landscape-scale logging in the San Lorenzo River watershed, around the turn of the previous century, imposed large-scale destruction of the old-growth forest ecosystem, and altered community structure and species interactions. By drastically altering local stream ecology, logging heavily impacted local salmonid populations (Spence et al., 1996). After clear-cutting, the forest grew back densely with trees of similar age and size. The resulting, more even-aged forest, is more susceptible to catastrophic fire. It also supports lower biodiversity, lacking the diversity of structural features associated with old-growth forests.

4.6.3.a Habitat degradation from logging

Little was recorded of the ecology and species prior to the clear-cutting in this area. Some species, still living in the region, such as the marbled murrelet (*Brachyramphus marmoratus*), undoubtedly had a much greater area of suitable breeding habitat prior to the almost complete removal of their primary habitat, old-growth forest.

Timbering has degraded riparian corridors throughout the watershed. Hardwoods have replaced conifers in many riparian areas. Downed wood from hardwoods tends to be smaller, more mobile, and shorter-lived than that derived from conifers and does not function as well in retaining sediment (Spence et al., 1996).

Table 4-7 summarizes the impacts of forestry operations on coastal streams, within the fog belt. (For more information about impacts outside the fog belt, refer to Table A-1).

Table 4-7. Coastal forest practices in the fog belt and their potential impacts to local coastal stream environments, habitat quality, and salmonid growth and survival

Forest practice	Types of potential impacts:		Potential consequences for salmonid growth and survival
	to physical stream environment	to quality of salmonid habitat	
Timber harvest in coastal riparian areas	Increased incident solar radiation	Increased stream temperature; higher light levels; increased autotrophic production; more food available	Reduced growth efficiency; increased susceptibility to disease; changes in growth rate and age at smolting- faster growth rate only if food supply overshadows metabolic costs of higher water temperature
	Decreased supply of large wood to the stream	Reduced cover; loss of pool habitat; reduced overwintering shelter from stormflows; reduced storage of gravel and organic matter; loss of hydraulic complexity	Increased vulnerability to predation; lower winter survival; reduced carrying capacity for juveniles; less spawning gravel; reduced food production; loss of species diversity
	Addition of logging slash (needles, bark, branches)	Short-term increase in dissolved oxygen demand; increased amount of fine particulate organic matter; increased cover	Reduced spawning success; short-term increase in food production; increased survival of juveniles
	Erosion of streambanks	Loss of cover along edge of channel; increased stream width; reduced depth	Increased vulnerability to predation; reduced carrying capacity and survival for juveniles
		Increased fine sediment in spawning gravels and food production areas; loss of cover from embeddedness of boulders; loss of cover from loss of deep water	Reduced spawning success; reduced food supply, reduced juvenile survival and carrying capacity
Timber harvest on coastal hill slopes; forest roads	Altered streamflow regime	Reduced summer baseflow due to lost fog drip; reduced retention of groundwater, aggradation of the streambed and faster transpiration rate of the younger forest after harvest	Decreased survival and reduced carrying capacity for juveniles
		Increased surface runoff during winter storms; increased peak stormflow events	Embryo and sac fry mortality caused by increased bed-load scour and movement
	Accelerated surface erosion and mass wasting	Increased fine sediment in stream gravels; streambed aggradation; increased turbidity from suspended sediment during important spring feeding period	Reduced spawning success; reduced food abundance; loss of rearing habitat and overwintering refuge, reduced feeding efficiency, slower growth, decreased survival and reduced carrying capacity for juveniles
		Increased supply of coarse sediment	Potentially increased spawning success and increased rearing capacity where large wood is present to segregate gravels and cobbles from fines
		Increased frequency of debris torrents; loss of instream cover in the torrent track; improved cover in some debris jams	Blockage to migrations; reduced survival in the torrent track; improved overwintering habitat in some torrent deposits
	Increased nutrient runoff	Elevated nutrient levels in streams	Increased food production
	Increased number of roads and crossings	Physical obstructions in stream channel; increased input of fine sediment from road surfaces and erosion from gully formation beside roads and landslides initiated by road failures	Restriction of upstream movement; reduced feeding efficiency, reduced rearing habitat, decreased survival and reduced carrying capacity for juveniles
Scarification & slash burning (preparation of soil for reforestation)	Increased nutrient runoff; Inputs of fine inorganic and organic matter	Short-term elevation of nutrient levels in streams. Increased fine sediment in spawning gravels and food production areas; short-term increase in dissolved oxygen demand	Temporary increase in food production. Reduced spawning success

Source: (Alley, 2008; Noss, ed., 2001).

In addition to problems noted in "Chapter 3: Hydrology, geomorphology & water quality," mass soil movement in forested watersheds is often triggered by road construction (Brown, 1991). The network of unpaved logging roads and skid trails in Santa Cruz County is an acknowledged problem (Santa Cruz County Planning Department, 1998). Roads built on slopes exceeding 50% often result in debris flows (Santa Cruz County Planning Department, 1998). Figure 4-15 shows a failed logging road in the Fritch Creek area of Boulder Creek. Fredriksen (1965, 1970) noted that landslides from mid-slope roads constructed across a patch-cut watershed produced sediment concentrations 34 times greater than expected from observations made during the pre-treatment period. Herbert (2004) cited the work of Trombulak and Frissell (2000), which summarized the ecological effects of roads of all types on terrestrial and aquatic communities, finding that:

> Not all species and ecosystems are equally affected by roads, but overall the presence of roads is highly correlated with changes in species composition, population sizes, and hydrologic and geomorphic processes that shape aquatic and riparian systems.

Figure 4-15. Logging road-cut failure on Fritch Creek

Collins, ca. 1998

Aftermath of logging on Fritch Creek, tributary to Boulder Creek, with evidence of road cut failure and bare, eroding slopes contributing sediment to ephemeral tributary.

Logging with heavy equipment and log skidding degrades the forest floor's moist duff layer, with its multitude of microbes, fungi and root systems that decompose and recycle nutrients in the leaf litter. Soil may become compacted, with overland water runoff increasing during storms.

Eroding soil from forests that are logged using selection cutting may enter stream channels and degrade both spawning and rearing fishery habitat, as illustrated in Figure 4-16 (Alley, 2008).

Following such practices, turbid conditions may last longer after storms, thus preventing visual drift feeding by salmonids. Removal of conifers in riparian corridors may reduce stream shading, and weaken streambank integrity provided by tree root systems. Logging along streams removes the source of large, durable instream wood that is critical for high-quality fishery habitat.

Figure 4-16. Selective cutting of conifers on steep slopes above a steelhead stream

Alley 1998

Disturbed slope, sun-exposed after selective logging of hillslope down to edge of headwater steelhead stream, Santa Cruz County.

4.6.3.b Loss of large instream wood after logging

As discussed in Section 4.4, large woody material is an essential part of a healthy aquatic habitat. Past clearcutting of old-growth redwoods resulted in a diminished recruitment of large woody material to streams, and current state logging regulations allow cutting and removal of existing redwoods every ten to twelve years.

According to the San Lorenzo River Salmonid Enhancement Plan (Alley et al., 2004a) the San Lorenzo River system has much less instream wood than other local steelhead and coho streams, including Gazos, Scott and Waddell Creeks:

> For example, Leicester (2005) found reach densities of large woody material (at least 1 foot in diameter) ranging between 18 and 65 pieces per thousand feet in the active (bankfull) channel of relatively small Gazos Creek. In surveyed reaches of the San Lorenzo and tributaries, the density range was only 2-32 pieces per 1000 feet (Alley et al., 2004a). One site, in Henry Cowell Park, had 65 pieces per 1000 feet.

4.6.4 Water diversions and pumping

In a climate where rain is seasonal, human demands for water compete with the need to maintain streamflow for biological systems. Human water demand peaks during summer and early fall when streams are experiencing their lowest flows of the year. In the San Lorenzo River, the disparity in timing that exists between the seasonal availability of water and the demand for its use has resulted in a complicated system of water storage systems, groundwater pumping, winter and summer diversion systems and cross-basin transport of water. Multiple agencies, including the District, distribute water to residents in the San Lorenzo Valley and other local communities (Alley et al., 2004a).

Streamflow is a limiting factor to salmonid populations. Streamflow is the primary element that defines total available habitat for salmonids, and to a large extent, determines habitat quality for juveniles related to habitat depth and food supply, with other limiting factors also affecting habitat quality and the ability to reach available habitat. For more information about the impacts of water diversions and groundwater pumping on salmonids, refer to Appendix A: Fisheries.

In the San Lorenzo River, the disparity in timing that exists between the seasonal availability of water and the human demand for its use has resulted in a complicated system of water storage systems, groundwater pumping, winter and summer diversion systems and cross-basin transport of water. Multiple agencies distribute water to residents in the San Lorenzo Valley and other local communities. The largest agencies are the City of Santa Cruz Water Department, California American (formerly Citizen's Utilities), the San Lorenzo Valley Water District, and the Scotts Valley Water District.

4.6.4.a Water diversions

The primary water diverter on the lower mainstem of the river is the City of Santa Cruz Water Department, which has three primary facilities that divert and store water. The systems include Loch Lomond Reservoir on Newell Creek, the Felton Diversion Dam a half-mile downstream of the Zayante Creek confluence, and the Tait Street Diversion near Santa Cruz, which includes streamside wells that can be used in place of diversion. Significant water diversions are also taken from tributaries to the San Lorenzo River. The largest diverter is the San Lorenzo Valley Water District, with its diversions from tributaries to Boulder Creek and Clear Creek. The

County's San Lorenzo River Watershed Plan documented impacts of municipal water use on fishery habitat as early as 1979 (County of Santa Cruz, 1979).

Additionally, the District diversion from Fall Creek draws water to serve the community of Felton. The Felton water system was operated by California American Water Company until its acquisition by SLVWD in 2008. The Lompico County Water District also diverts from Lompico Creek. For more information, see "Chapter 2: Overview of the District's Land & Water."

The District has not fully analyzed the potential impacts of its water diversions at different times of the year on aquatic habitat and fisheries in its own streams and on the larger San Lorenzo River.

There are also more than 130 individual private water diversions in the watershed. The potential impact of these is estimated to be relatively small (0.2-0.4 cfs.), given the small size of the properties and limited amount of irrigation where water is used (Ricker, 1979).

Each of these diversions collectively has an impact not only on local tributary stream conditions but has a cumulative impact on the middle and lower mainstem of the San Lorenzo River.

4.6.4.b Groundwater pumping

Another significant source of flow reduction that is much more difficult to monitor and quantify than diversions from creeks is groundwater well pumping. Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation.

Water diversion and pumping designed to maximize spring and summer streamflows would considerably benefit the production of larger juvenile salmonids in the mainstem river and the production of young juveniles and yearlings in tributary streams. This would, in turn, increase the number of returning adult steelhead and coho salmon as the spawning population.

4.6.5 Mining and quarries

Open pit mining is probably the most severe form of habitat removal and degradation. Entire mountains may be removed by mining. The geology, soils, and water table are also removed or altered by mining. Natural contours are removed and steep cliffs or cut banks are left at the property line of the quarry. Mines can be cut or restored to more natural contours (Spence et al., 1996).

Much of the already extremely rare and fragmented sandhills and sand parkland ecosystems have been removed and fragmented by sand pit mines, including approximately 1,200 acres of Ponderosa Pine parkland (San Lorenzo Valley Water District, 1985). According to the Sandhills Conservation and Management Plan:

> Since its inception during the first half of the 20th century, sand quarrying in the sandhills has occurred in six separate quarries. Three of these operations were completed decades ago, prior to the inaction of the Surface Mining Reclamation Act (SMARA) in 1975, and thus were not revegetated. They are the Scotts Valley Quarry (on Scotts Valley Drive), the Old Geyer Quarry (at the end of Geyer Road near Scotts

Valley), and the old Kaiser quarry that is part of the present day Olympia Wellfield managed by the San Lorenzo Valley Water District (McGraw, 2004).

Remaining sandhills and sand parkland are unmined on the "south ridge," in Quail Hollow County Park, within District lands, and a few other privately owned areas.

Quarries have been a source of sediment in water within the watershed for many decades. In response to Department of Fish and Game complaints about sand plant operations on Zayante and Bean Creeks releasing silt that adversely affected fisheries, the Department of Water Resources conducted a water quality study in 1957 (California Department of Water Resources, 1958). The purpose of the study was to provide data analysis for the CCRWQCB, then known as the Central Coast Water Pollution Control Board, to evaluate waste discharge conditions, and establish regulatory policies. It was common practice at the time for quarry operations to clean mined sand with creek water, and then store the sediment-laden by-product in settling ponds. At periods of high streamflow, they would open the gates on the ponds and flush them out into the creek, claiming no adverse impacts to water quality. The study was inconclusive, due to extremely high storm flows during the sampling period, and because sand plant operators prematurely released sediment, thereby precluding control sampling. However, even under these conditions, the scientists noted "a very noticeable difference in the color of the stream, above and below the discharge" (California Department of Water Resources, 1958).

Some quarries have had on going problems of excess sediment entering the streams from poor management, failure to follow rules or large storms compromising control efforts. Quarries are sources of excess sediment to streams, so prudent control measures, management and monitoring is necessary including agency monitoring and enforcement. Quarry operations in the Bean and Zayante Creeks subwatersheds, and in Gold Gulch, have substantially reduced sediment releases, since adoption of the original County Watershed Management Plan in 1979 (Hecht and Kittleson, 1998). Felton Quarry has been a source of dissolved minerals such as sulfate, iron, and manganese in the past (Camp, Dresser & McKee, 1996).

The Quail Hollow sand quarry is active. Both Hansen and Olympia quarries have closed and are implementing their reclamation plans. However, according to McGraw (2004), a plan was developed to restore sand parkland following mining at the Olympia Quarry, but the success criteria used to define restoration were not attained. As a result of this failure, it is generally considered impossible to recreate sandhills habitat (B. Davilla, pers. comm. 2002).

4.6.6 Recreational use

Off-road vehicle use and equestrian use have had a noticeable impact on the San Lorenzo River watershed. In sensitive habitats, such as District-owned Olympia watershed lands and conservation reserve areas within the Quail Hollow Quarry, recreational uses pose a significant risk to sensitive species. Due to the fragility and rarity of the sandhills species and communities, the impacts of recreation are disproportionately large in the sandhills relative to other systems in the region. Recreational use in undeveloped sandhills habitat results in plant cover removal, erosion, and threats to sensitive species populations in many sites (McGraw, 2004).

The District has not fully documented the impacts of recreational use on District lands on biotic resources.

Recreation impacts sandhills communities and species in various ways, depending on the magnitude (intensity and severity), areal extent, shape, and return interval of use (McGraw, 2004). Both the intensity of the recreation (the strength of the force) and the severity of the disturbance, (the degree to which biomass is removed) contribute to the magnitude of the disturbance. McGraw (2004) observed that on trails used for different types of recreation, the magnitude of disturbance increased with different types of recreation. Walking caused the least disturbance, followed equally by horse riding and mountain biking, and OHV riding causing the most disturbance.

The area of use influences disturbance impacts. Non-trail recreational use in which patches of habitat are transformed into arenas for gatherings, paintball wars, shooting, and OHV riding result in large areas being denuded. While wildlife and pedestrian trails are rarely incised, trails used by equestrians, mountain bikes, and OHVs are frequently incised where they occur in sloped areas (S. Singer, pers. comm. 2004, as quoted in McGraw, 2004).

The shape of the disturbed area, specifically the perimeter to area ratio, influences recreation impacts on habitat by affecting recolonization following disturbance. Arenas have a low perimeter to area ratio compared to trails, and wider trails characteristic of higher intensity uses (equestrians, OHVs) have greater perimeter to area ratios than narrow trails. This ratio influences the rate of recolonization following disturbance by determining the disturbance plants (and then animals) must disperse from adjacent, undisturbed habitat (McGraw, 2004).

Finally, the time between successive recreational uses determines the amount of time the system has to recover between disturbances, and so greatly influences the impact of recreation. If the time between trampling events is long enough, plants can recover and soil crusts can reform, such that the next disturbance will not further impact site conditions. However, because of the fragile nature of sandhills soils and plants, even low frequency recreation denudes trails (McGraw, 2004).

4.6.7 Chemicals and pesticides

Because sandhills soils are so porous, aquifers beneath these soils are especially vulnerable to chemicals, pesticides, and leachate from septic tanks, all of which have the potential to readily enter the aquifer and contaminate the water supply. Thus, use of herbicides to control and eradicate exotic plants in the sandhills must be carefully controlled (McGraw, 2004).

4.6.8 Exotic species

Urbanization, resource extraction, land disturbance and development of the San Lorenzo River watershed have introduced and aided in the proliferation of non-native plants and animals. Non-native species are detrimental to ecosystem functions and biodiversity.

The District has not surveyed and mapped exotic species on District lands.

4.6.8.a Exotic mammals

Exotic animals impact ecosystem functions. Of all the exotic species in the San Lorenzo River watershed, the feral pig is of particular concern, because it causes severe erosion and sedimentation. Feral pigs disturb the riparian zone as they dig and root. This activity leads to bank failure, slumping, and other geologic hazards within riparian areas. Feral pigs also transmit waterborne pathogens such as Giardia cysts and Cryptosproridium oocysts (Camp, Dresser & McKee, 1996). Feral pigs damage sensitive native plants and invertebrates. They reproduce quickly and are very hard to eradicate. State Parks is working to control feral pigs on lands owned by the department. While regional eradication is perhaps possible and certainly desirable, this is not the goal of this program (Hyland, 2007).

Feral pigs are known to inhabit the District's watershed lands, especially around Foreman Creek. The extent of the damage they have caused has not been estimated at this time.

Feral dogs and cats, which breed in the wild, may hunt and kill native species. Escaped pets of all types may reproduce and could also negatively affect the ecosystem.

4.6.8.b Exotic aquatic animal species

Crayfish are an invasive exotic species to the San Lorenzo River watershed. Crayfish were shipped in large batches to the California Fish and Game Commission Hatchery in Brookdale in 1912 in order to determine their negative effects upon young steelhead; and were later released into the San Lorenzo River (Cohen and Carlton, 1995). Non-native crayfish have changed the instream environment for native species such as steelhead, coho salmon and frogs. Some areas of the San Lorenzo River have large populations of non-native crayfish, which compete with steelhead for cover and food and may prey upon juvenile steelhead.

Bullfrogs, during their longer and larger tadpole stage, may prey upon native red-legged frog tadpoles. Adult bullfrogs prey on red-legged frogs at any life stage. Bullfrogs may also prey upon juvenile steelhead. Bullfrogs quickly proliferate, and are difficult to eradicate. Quantifying the effect of introduced bullfrogs on redlegged frogs is difficult. Undoubtedly, their role varies on a site-by-site basis. Doubledee et al. (2003) have developed a model to quantitatively measure bullfrog predation on California red-legged frogs. The model can potentially be used to assess individual sites. Bullfrogs are abundant in ponds at Roaring Camp, and have been observed as adults in Zayante Creek adjacent to the Trout Farm pond. Bullfrog tadpoles were captured in middle Boulder Creek in 2006 (Alley, 2006 pers. communication).

4.6.8.c Exotic invasive plants

Exotic (non-native) invasive species tend to take over and reduce plant diversity and spatial complexity.

Three local experts have documented non-native "exotic" plants in Santa Cruz County in a booklet entitled "A Plague of Plants: Controlling Invasive Plants in Santa Cruz County" (Moore, Hyland, and Morgan, 1998). Randal Morgan is a local taxonomic expert. Tim Hyland has worked in local resource management for many years. Ken Moore has led the Wildlands Restoration Team, which works with volunteers to eradicate non-native plants on public lands in Santa Cruz County since 1990. The authors describe the impacts of exotic plant species to the region:

> An exotic plant is simply a species that has been introduced into an environment different from that in which it evolved. While not all exotics are a problem, some are invasive; these are capable of displacing other species, thereby leading to their demise. Having left behind the predators and competitors that kept them in balance with other species at home, invasive exotics can proliferate unchecked, like a cancer on the land. The most invasive exotics can choke out native flora and provide no habitat value for

native fauna. They can form impenetrable thickets or mats, shading out the seedlings of native plants, competing for nutrients and water, or even fundamentally changing the soil to favor their kind. Most insects, birds, and other animals have adapted to use relatively few plant species for food, shelter, or nest sites. A loss of their preferred species can result in their decline or even extinction. If a sufficient number of species are eliminated, or even a few "keystone" species, the whole ecosystem can collapse. Some were introduced deliberately for their ornamental beauty, some came as contaminants in animal feed or as stowaways on stock animals' hides or hooves. Others were introduced speculatively for their supposed value as timber, or for erosion control. Many were brought here because of their ability to grow quickly, giving them yet another powerful advantage in out competing and forcing out native species.

Table 4.8 lists common invasive exotic plants found in the Santa Cruz Mountains.

Table 4.8 Common Santa Cruz County invasive exotic* plants

Plant type	Common name	Species
Herbaceous		
	Cape ivy	*Dilaireia odorata*
	Iceplant	*Carpobrotus edulis*
	English ivy	*Hedera helix*
	Algerian ivy	*Hedera canariensis*
	Bull thistle	*Cirsium vulgare*
	Italian thistle	*Carduus pycnocephalus*
	Yellow star thistle	*Centaurea solstitialis*
	Periwinkle	*Vinca major*
	Poison hemlock	*Conium maculatum*
	Wild fennel	*Foeniculum vulgare*
	Himalayan blackberry	*Rubus procerus discolor*
	Cocklebur	*Xanthium sp.*
	Forget-me-not	*Myosotis latifolia*
Grasses		
	Bermuda grass	*Cynodon dactylon*
	European dune grass	*Ammophila arenaria*
	Giant reed grass	*Arundo donax*
	Kikuyu grass	*Pennisetum clandestinum*
	Harding grass	*Phalaris aquatica*
	Common sheep sorrel	*Rumex acetosella*
	Common velvet grass	*Holcus lanatus*
	Hairy cat's ear	*Hypochaeris radicata*
	Big quakinggrass	*Briza maxima*
	Silver hairgrass	*Aira caryophyllea*
	Rat-tail fescue	*Vulpia myuros*
	Brome fescue	*Vulpia bromoides*
	Smooth cat's ear	*Hypochaeris glabra*
	Ripgut brome	*Bromus diandrus*
Trees		
	Monterey pine**	*Pinus radiata (non-native variety)*
	Eucalyptus, Tasmanian bluegum	*Eucalyptus globules*
	Acacia**	*Acacia spp*
Shrubs and brush plants		
	French, Spanish, Portuguese and Scotch broom	*Genista monspessulana and spp.*
	Pampas grass**	*Cortaderia jubata and Cortaderia selloana*

* Not native to this area; most not native to the United States.
** Poses heightened fire risk
Source: Moore et al., 2002; McGraw, 2004

Exotic plants of the redwood forest

During forest restoration efforts, exotic species are removed to restore healthy riparian function and native species diversity. Common invasive tree species include acacia and blue gum eucalyptus. Common herbaceous plants and shrubs include periwinkle (*Vinca major*), English ivy, bull thistle, Himalayan blackberry, poison hemlock, forget-me-not, and French broom. Most of these plants are present to some extent on District-owned lands.

Chaparral invasive plants

The most common invasive plants in the chaparral plant communities are French broom and pampas grass.

Exotic plants of the riparian woodlands

During riparian restoration efforts, exotic species are removed to restore health riparian function and native species diversity. Alley et al. (2004) documented invasive plant species along streams in Santa Cruz County. Common invasive, non-native tree species include acacia, Monterey pine, and blue gum eucalyptus. Common invasive herbaceous plants and shrubs include French broom, pampas grass, cape ivy (also known as German ivy) (*Senecio mikanoides*), English ivy, Himalayan blackberry (*Rubus discolor)*, nasturtium (*Nasturtium officinalis*), honeysuckle (*Lonicera* sp.), morning glory, giant reed grass (*Arundo donax*), cotoneaster (*Cotoneaster spp.),* and periwinkle.

Exotic plants of the sandhills and sand parklands

As in other sensitive plant communities, exotic plant species in the sandhills threaten native plants directly, through their competition, and indirectly, through their abilities to alter ecosystem structure and function (McGraw, 2004).

European annual grasses and forbs are the most abundant exotic plant species in the sandhills. European annuals are widespread and abundant in sand parkland, where predominantly open canopy conditions are conducive to their growth (McGraw 2004).

In sand parkland, the hotter, drier south-facing slopes are dominated by European *Vulpia* species (*V. myuros* and *V. bromoides*)*, Hypochaeris glabra,* and to a lesser extent *Bromus diandrus.* While *H. glabra* is also abundant on north slopes, another diminutive grass, *Aira caryophyllea* dominates the cooler slopes. *Briza maxima* prefers to grow underneath pines and sometimes underneath oaks. The litter from both types of trees greatly reduces the abundance of both *V. bromoides, V. myuros,* and *H. glabra* (McGraw, 2004).

Many aggressive European perennial grasses and forbs found throughout Santa Cruz County have yet to invade the sandhills, suggesting that the sandhills may indeed have some abiotic resistance to invasion due to a combination of hot dry summers and low nutrient conditions. Two exceptions to this trend are *Hypochaeris radicata* and *Rumex acetosella*, which are found in the more mesic microsites in sand parkland. While *H. radicata* is relatively rare, *R. acetosella* is patchily very abundant under trees and on north slopes in sand parkland (McGraw, 2004).

A third noteworthy exception to the trend is the recent invasion of *Holcus lanatus* into the sandhills. Well known for its ability to invade and quickly dominate wet grasslands and meadows, this European perennial grass is rapidly becoming one of the most abundant exotic plants in mesic grasslands communities in central California, including Santa Cruz County (McGraw, 2004).

Aggressive shrubs and trees as well as the shrub-sized pampas grass (*Cortaderia jubata;* have invaded many sandhills sites. Large exotics including *Acacia dealbata, Eucalyptus* sp., *Cytisus multiflorus*, *C. scoparius,* and *Genista monspessulana,* are often found along roads and have become established on the perimeter of many sandhills habitat patches. *Acacia dealbata* became established and abundant at the old quarry of the Olympia Wellfield. Also in the Fabaceae, this tree not only has a persistent seedbank, but readily 'stump sprouts' such that simply cutting the tree at the trunk does not kill the plant, though techniques for eradicating this aggressive invader are being developed (McGraw, 2004).

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CHAPTER 5: FIRE MANAGEMENT

5.0 Introduction

Fire is part of an important cycle of natural processes in both plant communities and watersheds. Historically, fire has played a significant role on the watershed lands now owned by the District, both in the forested areas on Ben Lomond Mountain, and in the sandhills plant communities of the District's Olympia Wellfield.

In forested areas, fire has historically contributed to a patchy forest age structure. Patchiness increases the overall health and resilience of the forest through time. Fire regimes vary according to climate, geography, vegetation types, and management practices. The fire regime of the past hundred years has emphasized fire suppression.

Ongoing climate change is an increasingly serious concern for watershed managers. Scientists have reported that the warmer and windier conditions corresponding to a doubling of carbon in the atmosphere produce fires that have burned more intensely and spread faster in Northern California (see Paragraph 5.8, Modeling fire).

Climate change is likely contributing to increased frequency and severity of wildfires locally, despite fire suppression efforts. Potential impacts to watershed resources from three large Santa Cruz County wildfires in 2008 are discussed in a post-fire study which brings to light many concerns for watershed managers should wildfires continue to increase as a result of climate change (see Paragraph 5.1, 5.1 Historical fire regimes in the Monterey Bay Area).

Drier inland forested areas are more prone to fire than moister coastal forests. Forests in areas of high wind are prone to windthrow, which create a significant fuel load.

Forests that are predominately redwood *(Sequoia Sempervirens)* are able to resist the effects of all but the most intense wildfires (Agee, 1993). Because it is the driest time of year, critical fire weather typically occurs in July through October. However, CalFire historical files for the Santa Cruz Mountains indicate that extreme fire conditions, including low humidity and high winds, have frequently occurred from August through early January. For example, in January 1961 six fires were recorded, several of which covered more than 1,000 acres (CalFire, 2008). Typically, redwood forests in the region also include Douglas fir (*Pseudotsuga menziesii*), tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and California bay (*Umbellularia californica*). Redwoods are not fire dependent; that is, they can survive and regenerate without fire.

In terms of fuel, redwoods are relatively free of volatile oils and resins, making them somewhat fire-resistant (Lindquist, 1974; as cited by Agee, 1993). Redwoods thrive in coastal areas with summer fog, which helps to lessen fire hazard. In mature upland stands, low intensity fires generally do not kill the overstory conifers, but will kill the tanoaks and other trees (Agee, 1993). Moderate severity fires that scorch the crowns of overstory conifers will generally kill mature Douglas firs, but not redwoods, which will re-sprout and grow a new crown (Agee, 1993).

Sandhills chaparral communities have undergone the most dramatic shift in structure due to plant succession in the absence of fire. Aerial photographs during the past 60 years have revealed large increases in woody vegetation and concomitant reductions in open sand areas during this period of fire suppression. The resulting increase in canopy closure reduces the abundance of open sandy habitat required by important sand chaparral plant species. Research suggests that plants cannot complete their life cycles in the dense leaf litter and low light of the closed canopy environment (McGraw, 2004).

Canopy gaps important for maintaining plant diversity are likely also important for the sandhills fauna, which is impacted by canopy closure due to fire exclusion. Animals may rely on the gaps in the canopy which provide habitat conditions dissimilar from the closed canopy environment including a greater availability of sunlight (e.g. for thermoregulation) and a higher diversity of plants which may provide a variety of food sources not found in the closed canopy (e.g. flowering plants for pollinators, seeds of herbaceous plants for granivores, etc.). Indeed, shrub encroachment due to fire suppression in sandhills chaparral communities is cited as one likely cause for the likely extirpation of the Santa Cruz kangaroo rat from the Bonny Doon Ecological Reserve and Wilder Ranch sandhills sites during the past 20 years (Bean 2003).

With respect to watersheds, major wildfires are important aspects of bed sedimentation, erosion and aquatic habitat management throughout the Coast Ranges (Hecht and Kittleson, 1998). Fire suppression and the resulting absence of wildfire over the last few decades increase the chance of a major fire, which could seriously alter surface hydrology and sedimentation (Balance Hydrologics, 2007).

5.1 Historical fire regimes in the Monterey Bay Area

Wildfire has long been both a natural occurrence, as well as a land management tool in the Santa Cruz Mountains, since the earliest inhabitants arrived between 30,000 to 10,000 years ago (Balance Hydrologics, 2007).

The year 2008 was a significant year for wildfires in Santa Cruz County. In May, the Summit fire burned 4,270 acres in the Browns, Corralitos, Soquel, and Uvas Creek watersheds (State Emergency Assessment Team (SEAT), 2008). In August, the Martin fire burned 520 acres at the Bonny Doon Ecological Preserve in the San Vicente Creek and the Laguna Creek watersheds (SEAT, 2008). SEAT reports conduct rapid assessments on burned areas of wildfires, as well as downstream of burned areas to determine if emergency rehabilitation treatment is needed to minimize risk of threats to human life or property, to minimize or prevent deterioration of water quality, loss of soil productivity due to erosion, or degradation of wildlife and botanical habitat, and cultural resources.

The SEAT report (2008) found that the principal concern in the aftermath of the Summit Fire was an increase in the potential for in-channel floods, hyper-concentrated floods, debris torrents, and debris flows. The primary mechanisms for these problems were found to be:

1. The loss of mechanical support of hillslope materials provided by vegetation and vegetative litter;
2. The increase in runoff resulting from reductions in interception and infiltration from the simplification of surface runoff patterns;
3. The loss of mechanical support along stream channels where riparian vegetation was burned.

Stephens and Fry (2005) provided a literature review tracing the history of fire in the Santa Cruz Mountains, and documented fire history by analyzing ring counts on live trees, downed logs, and stumps. Native inhabitants burned scrub and grasslands to foster the growth of seed-bearing annuals, and to facilitate acorn gathering (Balance Hydrologics, 2007). Logging operations from the late 1800s to the early 1900s relied heavily on fire to reduce slash piles, and to clear land for conversion to grazing and home sites. Fire scars on old growth redwood stumps throughout the watershed serve as historical evidence of these practices (Balance Hydrologics, 2007).

Greenlee and Langenheim (1990) distinguished five different historical fire regimes in the Monterey Bay area, which they based on field research they conducted in Big Basin State Park:

- Lightning Regime – up to 11,000 before present (BP)
- Aboriginal Regime – 11,000 BP - 1792 A.D.
- Spanish and Mexican Regime – 1792 – 1848
- Anglo Regime – 1848 - 1929
- Recent Regime – 1929 - present.

5.1.2 Lightning Regime

During the lightning fire regime, humans were not yet part of the ecosystem, and lightning accounted for all of the fire ignitions. Over a 50 year period, lightning fires were estimated to cover approximately 37 percent of the redwood forest, over approximately 20 percent of the land surface of Santa Cruz County. The mean fire interval (MFI) in the redwood forests was approximately 135 years (Table 5.1).

5.1.3 Aboriginal Regime

Upon arrival of humans, lightning was no longer the main source of fire. People used fire as a management tool. Greenlee and Langenheim (1990) suggest that one of the primary disturbances to vegetation communities resulted when humans arrived and practiced their local fire regimes.

Native Americans were nomadic, depending on the seasonal availability of foods. They burned oak savannah and coastal prairie to increase the productivity and collection of acorns, bulbs and other edible plants. The mean interval between fires shortened as a result (Table 5.1). To avoid grizzly bears, humans did not often venture into the redwood or mixed evergreen forests (Greenlee and Langenheim, 1990). However, some of these fires would spread into the forest.

Prior to the arrival of European man, forest fires were mostly low intensity ground fires that did not burn into the conifer live crowns. Fires set by Native Americans would burn through the forest often enough to prevent the accumulation of high fuel loads on the forest floor or the occurrence of dense ladder fuels that would carry flames into the canopy. During extreme fire weather, crown fires would still occur, but they would be infrequent events (Agee 1993).

5.1.4 Spanish Mexican Regime

During the Spanish Mexican Regime, the Spanish primarily burned chaparral, in order to increase grazing areas on their ranches. Traditional use of fire by the native Ohlone was made illegal.

5.1.5 Anglo Regime

During the Anglo fire regime, loggers burned to reduce slash, to ease the removal of downed logs, and to convert logged land to other uses. Greenlee and Langenheim (1990) describe fires from logging practices during this era:

> Since control lines were not used, fires frequently escaped. Where these human-caused fires burned under extreme weather conditions in heavy fuels, they were not usually stopped by a change in weather or by minor barriers.

Newspapers from this time described these fires as large, intense conflagrations, which frequently became crown fires (Greenlee, 1983). Fires often escaped control; by 1888 the State Forester considered escaped logging fires to be a major problem (Anonymous, 1888). Fire scars dating from the Anglo regime indicate that the entire inland portion of the county was logged and burned at least once and, in many places, two or three times. In contrast to the Aboriginal and Spanish regimes, fires during the Anglo regime generally occurred in the inland rather than in the coastal zone, and were larger, more frequent and more intense than previous lightning fires.

According to historical records, Santa Cruz County has one of the lowest numbers of recorded lightning fires in California (Keeley, 1981, as cited in Greenlee and Langenheim, 1990). Between 1893 and 1979, only 101 lightning storms were recorded for the County, igniting 34 fires (Greenlee and Langenheim, 1990). Ninety-one of these storms occurred during the moist winter season, causing only one fire. The remaining 10 storms caused the remaining 33 fires (Greenlee and Langenheim, 1980 as cited in Greenlee and Langenheim, 1990).

5.1.6 Recent Regime

As the watershed became increasingly developed, fire suppression became an accepted management goal. Land managers were advised to eliminate fire in old-growth forests and to be more careful when burning cut-over lands:

> The virgin redwood forest has been irreparably damaged by past fire; current fires aggravate the damage and on cut-over land they materially reduce the value of the land for new tree growth (Fritz, 1931; as quoted in Stephens and Fry, 2005).

According to Stephens and Fry (2005), "This early viewpoint was biased towards the utilization of redwood trees for lumber." Still, from 1929 to 1979, some 3,765 fires burned approximately 53,000 acres, approximately 19 percent of the County's land base (Greenlee and Langenheim, 1990). Ninety-two percent of these fires were less than 10 acres (Greenlee and Langenheim, 1990).

Fire suppression altered the natural processes of fire, reduced habitat variability, and impaired natural mechanisms necessary for ecosystem health. Fire suppression and clear-cutting altered forest structure and removed the patchy mosaic of various plant communities. The resulting build-up of ignitable fuel material on the ground increased the risk of a catastrophic fire.

Fire suppression affected other vegetation types in the watershed even more severely than it affected redwood and mixed conifer forests (Greenlee and Langenheim, 1990). In the sandhills, fire suppression is drastically altering the community structure of this rare ecosystem, potentially endangering it existence. McGraw (2004) conducted research to test the response of sand parkland vegetation to manual removal of pine needle litter from the soil, safely mimicking the effects of fire. Her results showed a positive response from native annual vegetation to this management technique.

Changes in the frequency and severity of wildfires will alter the composition, structure, and function of redwood forests. Fires suppression, practiced since the late 1920's, has increased the density of tan oaks and other hardwoods in the forest understory. It has likely cut off the recruitment of large snags and large down logs, two elements that play important roles in old-growth forest ecosystems.

Climate change and the build-up of forest fuels caused by Sudden Oak Death disease may cause the fire frequency "pendulum" to swing to the other extreme, as there is expected to be an increase in the frequency and severity of wildfires (U.C. Coop. Ext. 2008, Westerling and Bryant 2008). One possible scenario foresees more crown fires of an intensity severe enough to kill all the Douglas-firs and understory trees and burn the redwoods so severely that they won't sprout from the trunk and will only survive as stump sprouts. If this occurs, all large live trees will be lost from the stand. If severe fires re-occur frequently enough, old-growth conditions may never be re-established without human intervention, as the first conifer to achieve old-growth characteristics is Douglas-fir and it takes at least 175 years to reach that state.

Table 5.1 Mean fire intervals (MFI) in various vegetation types by historic fire regime in the Monterey Bay area

Fire regime	Vegetation where burning concentrated	Vegetation where burning incidental	Recorded or calculated MFI (yr)[1]	Probable MFI (yr)[2]
Lightning		Prairies		1-15
		Coastal sage		1-15
		Chaparral		10-30
		Oak woodland		10-30
	Mixed evergreen			30-135
	Redwood forest		135	
Aboriginal	Prairies		1-2	
	Coastal sage		1-2	
		Chaparral	18-21	
	Oak woodland		1-2	
		Mixed evergreen		50-75
		Redwood forest	17-82	
Spanish		Prairies		1-15
		Coastal sage		1-15
	Chaparral		19-21	
		Oak woodland		2-30
		Mixed evergreen		50-75
		Redwood forest	82	
Anglo		Prairies		20-30
		Coastal sage		20-30
		Chaparral	10-27	
		Oak woodland	50-75	
	Mixed evergreen		7-29	
	Redwood forest		20-50	
Recent		Prairies		20-30
		Coastal sage	155	
		Chaparral	155	
		Oak woodland	225	
		Mixed evergreen	215	
		Redwood forest	130	

[1] Recorded or calculated MFI data are derived from historic documents, fire scars, or published data.

[2] Probable MFI data, due to a lack of historic or physical evidence, are derived from data from literature.

Source: Greenlee and Langenheim, 1990.

5.2 Fire in the San Lorenzo River watershed

The San Lorenzo watershed contains substantial areas of fire-adapted vegetation, reported to burn at historical intervals of typically 40 to 80 years (Hecht and Kittleson, 1998). Fire suppression has been the predominant management strategy in the San Lorenzo River watersheds since the era of slash burning. CalFire is responsible for fire suppression and management in State Responsibility Areas (SRAs) and the Santa Cruz County Fire jurisdiction. Other fire districts, including Boulder Creek, Felton, Ben Lomond, Branciforte, Zayante, University of California at Santa Cruz, Scotts Valley and City of Santa Cruz, are responsible for fire management in their own jurisdictions within the watershed.

Several fires occurred in the 1930s and 40s, and a large fire known as the Sawmill Fire burned in the 1950s (Balance Hydrologics, 2007). In 1959, a fire in the Loch Lomond watershed burned about 1,000 acres on both sides of the lake. Evidence of this fire can be seen on the east side of Loch Lomond, where residual burned snags tower above the living trees. The Love Creek fire burned in 1970. No major wildfires have occurred in the watershed in the last three decades (Balance Hydrologics, 2007). Numerous small fires have occurred, but they have had little effect on reducing the overall fuel load (Balance Hydrologics, 2007). Therefore, there is concern among local resource managers that fire suppression has created a fuel build-up that will result in a watershed-scale fire, if the conditions are right (Balance Hydrologics, 2007). (Refer to Section 5.4, Forest Management and Fire and in the Santa Cruz Mountains).

5.3 Potential impacts to water resources from wildfire

Most water purveyors drawing upon surface or spring supplies should anticipate extended turbidity events following a large fire in their watersheds. Planning should focus on exploring potential alternative sources of supply during the months or years following the fire, and for protecting diversion or distribution facilities from post-fire erosion and slope stability (Balance Hydrologics, 2007).

5.3.1 Expected aftermath of a high intensity fire at the watershed scale

The SEAT report (2008) described the threats to water quality in the aftermath of the 2008 Summit fire in the forested areas of southern Santa Cruz County. The report stated:

> Water resources located within or near the fire perimeter are at an increased risk to the threat of flooding, debris torrents, and debris flows. The risk appears to be greatest to the City of Watsonville water supply. Watsonville maintains water intakes on Corralitos and Browns Creek (SEAT, 2008).

The report also found threats to wildlife, botanical resources and fisheries, due to the increased threat of flooding, debris torrents, and debris flows. Threats were greatest to listed species and species of special concern.

A major fire in the San Lorenzo River watershed could have serious consequences for the watershed health and water quality, the following areas:

- Alteration of surface hydrology and sedimentation
- Chemical impacts from fire retardants
- Habitat degradation and loss

5.3.1.a Alteration of surface hydrology and sedimentation

A major fire would cause alteration of surface hydrology and sedimentation in any or all subject water supply streams (Balance Hydrologics, 2007). First, sediment input into streams within the watershed would be increased for years, due to the loss of vegetation and canopy. High intensity fires burn organic matter within the soils. Since this organic material helps to hold soils together, burning increases the susceptibility of newly exposed soils to erosion (Spence et al., 1996). Burning can also cause soil to become hydrophobic, increasing runoff and erosion (Spence et al., 1996). According to the 2007 watershed sanitary survey:

> Elevated levels of turbidity are likely to persist from several months to several years following an extensive fire. Only part of the time will levels remain elevated about 10 to 30 NTUs (nephelometric turbidity units), a rule-of-thumb threshold range above which reliable water treatment becomes more challenging (Balance Hydrologics, 2007).

Creation of temporary roads and firebreaks to control fires can be a source of persistent sedimentation and turbidity if not properly abandoned following fire events. Reseeding burned slopes, mulching exposed soils, and the use of other erosion control techniques will reduce, but in no way eliminate the significant erosion likely to follow a wildfire (Balance Hydrologics, 2007). In addition, reseeding with non-native plants has potential impacts to native plant community regeneration.

5.3.1.b Chemical impacts to water quality from fire retardants

Fire retardants may also have adverse effects on water quality. Historically, retardants used by CalFire have included borate salts and bentonite clay in water. Borate salts are long lasting, but they are also phyto-toxic and soil sterilants. Bentonite clay in water is less persistent. Use then shifted to ammonium-based fire retardants, which accounted for nearly all chemical retardants used to control wildand fires. When these chemicals are applied directly to stream surfaces, they may cause fish mortalities (Buhl and Hamilton, 1998) and alter aquatic conditions by elevating nitrogen and causing eutrophication downstream (Camp, Dresser & McKee, 1996). More recently, a powder-based product (AquaGel-K) has become the dominant material applied by CalFire aircraft (CalFire, as documented in Balance Hydrologics, 2007). The active ingredient in this gel fire retardant, 2-propenoic acid, is practically non-toxic to aquatic organisms and the material degrades readily in sunlight. It also has enhanced reflectivity, which increases its effectiveness in combating initial outbreaks of fire (Balance Hydrologics, 2007).

The fire suppressant foams applied by fire trucks and helicopters may also have adverse impacts on water quality, and are more toxic to aquatic biota than ammonium-based fire retardants (Gaikowski and others, 1996 as cited in Balance Hydrologics, 2007). Application requires leaving a buffer between the spray zone and live streams (Balance Hydrologics, 2007).

5.3.1.c Habitat degradation and loss

Sedimentation and erosion in the aftermath of a major fire could have devastating impacts to fisheries and wildlife habitat. Steelhead and coho salmon are already listed as threatened or endangered, due in part to sedimentation in their natal streams. The impacts of fire retardants would also further threaten the survival of these fish, and other aquatic species. A fire that destroyed the forest canopy would also impact bird and mammal species.

Recovery of habitat in streams of the San Lorenzo River watershed following a high intensity fire would be expected to take 3 to 5 years (Hecht and Kittleson, 1998).

A catastrophic fire creates conditions to which native species are not adapted. The higher intensity and/or severity of a catastrophic fire could have devastating impacts on native species, which may be adapted to less intense fire conditions.

5.3.2 Expected aftermath of a high intensity fire on District-owned lands

The SEAT report (2008), which described threats to the City of Watsonville's water quality in the aftermath of the Summit Fire could be instructive to the District.

Potential pollutants generated from a fire in residential areas upstream of the District's water intakes on Foreman and Clear Creeks could have significantly more impact on water quality than pollutants generated solely from a forest fire.

The District's ground water sources located in the sandhills areas are especially prone to catastrophic fire. Because the sand soils are so porous, any residues left from the fire or chemicals used in fire fighting have the potential to readily enter the aquifer and thus contaminate the region's water supply. State Parks plans to increase prescribed burns in the pine sandhills areas of the Majors Creek watershed (Balance Hydrologics, 2007).

Generally, most of the expected impacts discussed at the watershed scale could also be expected for the District's watershed lands. However, because elevated turbidities persist much longer in reservoirs than in streams, the District's major surface water sources from local tributaries would probably have a shorter recovery time than the surface water source at Loch Lomond.

5.4 Fire management jurisdictions and practices

In rural areas, outside the jurisdiction of local fire districts, fire management within the San Lorenzo River watershed is the responsibility of the California Department of Forestry and Fire Protection (Cal Fire), Felton Headquarters (Camp, Dresser & McKee, 1996). The agency is equipped to suppress wildland fires throughout the watershed.

Local fire districts take primary responsibility for fighting domestic and commercial fires within their jurisdictions. At the county level, the county fire marshal is responsible for the coordination between neighboring fire districts, particularly during first alarm response. The county Office of Emergency Services provides communication and warning services to area residents and fire districts (Balance Hydrologics, 2007).

The stated fire management objective of the County General Plan is "to protect the public from the hazards of fire through citizen awareness, mitigating the risks of fire, responsible fire protection planning, and built-in systems for fire protection and suppression."

The Santa Cruz County Fire Department and the Office of Emergency Services participate in the development of fire-related development standards and post-fire restoration efforts, in addition to the review and updating of the countywide Disaster Contingency Plan and Critical Fire Hazard Maps.

Prescribed burning by the state Department of Parks and Recreation at Henry Cowell Redwoods State Park and Big Basin State Park is conducted to minimize the potential spread of a major fire either into or out of the parks. Prescribed burns are also used to promote fire-tolerant native vegetation threatened by invasive non-natives (Balance Hydrologics, 2007).

Balance Hydrologics (2007) described prescribed burning within the watershed, in order to address the potential catastrophe of a watershed-scale wildfire:

> Prescribed burning is done by the California Department of Parks and Recreation at Henry Cowell Redwood State Park and in Big Basin Redwoods State Park. These prescribed burns are done for two primary reasons: (1) vegetation management within Park boundaries and (2) to reduce the likelihood of fires passing over the Park boundaries. Use of prescribed burns is expected to increase over the next five years with the parks (Tim Hyland, personal communication, as documented by Balance Hydrologics, 2007). Many large forest landowners maintain networks of fire trails and roads on the properties. The County, and a number of community organizations including the former Fire Safe Council, attempt to extend appropriate measures to willing owners (Balance Hydrologics, 2007).

While fire suppression remains the primary fire management goal, Cal Fire's Vegetation Management Program staff (VMP) regularly work with landowners, including State Parks, on prescribed burns in the watershed. VMP staff also regularly work with other landowners, including the Los Cumbres and the Indian Trails homeowners associations, on vegetation management projects. In addition, the SCCRCD staff assists landowners with fire trail maintenance projects throughout the watershed.

Other agencies and landowners of large tracts of watershed lands could utilize prescribed burns as a management tool. More public education about fire prevention and management is needed to assist landowners in managing private property and to prepare for a large fire.

5.5 Forest management and fire in the Santa Cruz Mountains

Commercial timber harvesting in the Santa Cruz Mountains, which focuses on cutting of large and/or mature redwoods for their commercial value, is often presented by local foresters as a method of reducing fuel load and fire hazard. However, many scientists have refuted these claims. According to Montague (2006):

> Mature coast redwood stands usually will not support a crown fire without a heavy accumulation of ground fuels. Thinning of these mature Douglas fir and coast redwood trees to reduce the potential for a crown fire is not economically sound. The closed crowns and local fog conditions maintain the ground fuels to a much higher live and dead fuel moisture condition; therefore, producing a low fire spread and intensity. To open up the normally dense crown cover to more sunlight and solar heating will reduce live and dead fuel moistures, thereby increasing fire spread, fire intensity and flame lengths.

It is important to note that the goal of a commercial timber harvest plan is to realize revenues from timber; hence, a commercial timber harvest plan emphasizes the removal of large trees with high timber value, which are also the most fire-resistant trees. In contrast, thinning the forest to reduce fuel load emphasizes the removal of smaller ladder fuels. These smaller trees have relatively little timber value.

It should be noted that much of the area that burned in the 2008 Summit fire had been recently logged, including the property known as Grizzly Flat, owned by the City of Watsonville. In the mid-1990s, the city conducted a 120 acre commercial timber harvest plan at Grizzly Flat that removed many of the biggest and oldest redwood trees, just above the city's water intake on Corralitos Creek. Opponents to the timber harvest plan argued unsuccessfully that the logging would threaten the city's water quality (Herbert, 1995).

Omi (2006) stated that lopping and distributing fuels may increase fuelbed continuity and spread rate, depending on extent and quality of execution.

Analyzing the potential impacts of fire from a proposed a 1,000 acre timber harvest plan in the Santa Cruz Mountains, Montague (2006) stated:

> Timber harvesting techniques used in the region's selective harvesting regime, including cable, helicopter and tractor yarding, create activity fuels which will burn at a much higher rate of spread, fire intensity and produce longer flame lengths than if 100 year-old Douglas fir and coast Redwood stands are left in their current state. Activity fuels debris from timber harvesting activities such as road clearance (stumps and tree debris), treetops and limbs left on the ground, down and broken undergrowth brush and young trees (sapling and pole size trees). Activity fuels created by the various recommended timber harvesting techniques tend to increase overall fuel loading and fire intensity (Montague, 2006).

Montague (2006) recommended the following forest management regime as more appropriate than the proposed selective harvesting:

> What would be more appropriate for reducing and/or minimizing fire spread and intensity in the coast redwood and Douglas fir stands is to reduce ground fuel loading rather than crown removal. This can be accomplished by hand labor, mechanical means and/or the use of prescribed fire. Thinning out the understory ground fuels will do more to reduce fire spread and intensity than crown removal by timber harvesting (Montague, 2006).

Commenting on the same proposed logging plan, Stephens (2006) reported:

> Removing forest canopy by thinning this forest would not effectively reduce potential fire behavior and effects, especially in areas where redwood is the dominant species. Redwood foliage is not particularly flammable and there are few records of crown fires in redwood forests.

According to Stephens (2006), the most effective way to lessen potential fire intensity in redwood forests is by reducing woody surface fuels, and the best method for reducing woody surface fuels in redwood forests is by using prescribed fire:

> Experiences in prescribed burning in redwood forests demonstrate the sensitivity of this forest type to changing weather conditions. A minimum relative humidity of 50 percent is needed to successfully burn redwood litter (Finney, 1991; Stephens and Fry, 2005). It is possible to burn under higher humidities into the early evening for approximately 30 minutes, but once relative humidity increased to 60 percent, burning is no longer possible. Redwood responds very quickly to relative humidity changes. With heavy fog in the morning, it is possible to burn by 2 p.m. in the same afternoon if off-shore winds are present (Stephens, 2006).

According to Swanson Hydrology and Geomorphology (2001), logging increases fire risk for several reasons. First, harvesting typically removes the biggest trees, which are the least combustible, and which provide shade. Thus, timber harvesting enables increased penetration of solar radiation to the ground, which can reduce fuel moisture and humidity. Increased sunlight also encourages significantly faster understory growth, along with higher levels of stored chemical energy. This increased understory growth, in turn, "increases continuity of the vertical and horizontal fuel array." When the relatively large trees are cut, and replaced by smaller ones, the average height to the base of the tree canopy is also reduced, enabling transition from understory to crown fire. After logging, even-aged stands of small conifers result with uniform, dense canopies that also increase fire severity (Frost and Sweeney, 2000). Finally, logging slash can greatly increase dead fuel loads, and the increased hazard of crown fires may persist for many years following logging.

5.5.1 Forest management and fire in the San Lorenzo River watershed

Swanson Hydrology & Geomorphology (2001) characterized vegetation and assessed its role as potential fuel on the City of Santa Cruz watershed lands, which are located in the San Lorenzo River watershed. By analyzing data from local sources, they characterized vegetation in various areas as "fairly dense growth of young redwood," low density Douglas fir, chaparral, hardwoods, and knobcone pines. Following repeated logging by the city of Santa Cruz, Tunheim (1994) measured redwoods and Douglas fir, finding that they were predominantly 12 - 24 inches in diameter at breast height Swanson Hydrology & Geomorphology (2001) stated that, "it is clear from the timber data that the vegetation of the watersheds has been greatly modified by timber harvest and related activities. This will profoundly affect potential fire behavior."

Swanson Hydrology & Geomorphology (2001) documented the effects of timber harvest on subsequent fire behavior with empirical evidence from other forested areas. Citing Agee (1993) they found that, in Pacific Northwest forests that have been logged, excessive densities of Douglas fir can occur during early stages of regeneration. This growth not only hinders successful reestablishment of redwoods, but also creates a post-harvest fuel structure that may be conducive to stand-replacing wildfires for many decades. The authors also cited a comprehensive analysis of forest management in the U.S. (Aber et al., 2000), which concluded that forests with logging are more vulnerable to fire, and suffer greater consequences after fire, in terms of tree mortality and post-fire sedimentation, when compared to unmanaged forests. The authors found an apparent "consistent relationship between logging and increased negative effects related to fire."

Hydrology & Geomorphology (2001) found that, considering all of these factors together within the City of Santa Cruz watershed lands, that the area did have the potential for crown fire when weather conditions are favorable to combustion. The authors attributed recent changes in fuels more to timber harvesting than other factors. They found that "only riparian areas and pockets of late seral forest may currently retain a natural tendency to support surface fire or mixed fire severity" on city watershed lands. They also found it likely that similar scenarios exist in the Newell Creek watershed, upstream from the city's land.

5.5.2 Forest management and fire on District lands

While CalFire staff has assessed District lands for fire hazard severity (Figure 5-1), the District has not retained a fire management consultant to assess its forested watershed lands on Ben Lomond Mountain for fire hazard severity or for risk of ignition. The District's forested properties have not been recently logged, and most are approaching late seral stage. Thus, they may be less vulnerable to fire than the city of Santa Cruz watershed lands, though as Figure 5.1 indicates, almost all of the District's service area, on the west side of the San Lorenzo River, is rated by CalFire as high fire hazard.

5.6 Assessing fire hazard and risk

The District has not yet mapped and analyzed fire hazards more precisely than CalFire's broad maps, in order to conduct a wildfire risk analysis and develop specific emergency response readiness for fire.

Fire hazard assessment is based on the physical conditions of an area making it likely to burn over a 30 – 50 year period, without considering modifications such as fuel reduction efforts (CalFire, 2007). Risk, on the other hand, is the potential damage a fire can do to the area under existing conditions, including any modifications such as defensible space, community-based fuel modification or fire beaks, building construction, irrigation or sprinklers (CalFire, 2007).

In 2007, CalFire's Office of the State Fire Marshall revised its maps that identify wildfire hazard in areas, including unincorporated areas of Santa Cruz County, for which the State has financial responsibility for wildland fire protection. Figure 5.1 shows CalFire's 2007 map of fire hazard severity zones for Santa Cruz County.

CalFire has mapped three hazard ranges: moderate, high and very high. Wildfire hazard areas are areas of significant fire hazard based on fire history, potential fuel over a 30- to 50-year period, blowing embers, terrain, and weather. Note that most of the District's watershed land, on the west side of the San Lorenzo River, is shown as high fire hazard.

The 2007 fire hazard maps will be used to implement new wildland-urban interface building standards adopted by the California Building Standards Commission. The new building codes establish ignition-resistant construction for roofing, walls, decks, windows, and other building elements for homes in the wildland-urban interface based on the area's fire hazard severity zone classification (CalFire, 2007).

Swanson et al. (2002) emphasize that fuel characteristics have only moderate impact on fire hazard, which is strongly influenced by ignition patterns and weather conditions. Estimating fire hazard, in terms of lives and residential structures, requires assessment of local topography, adjacent fuels, the potential for structures to ignite, and the existence of escape routes from dwellings and neighborhoods.

According to invasive plant removal specialist Ken Moore, the invasive populations of French broom on District property at the Olympia Wellfield have increased the risk of catastrophic fire (Moore, 2007).

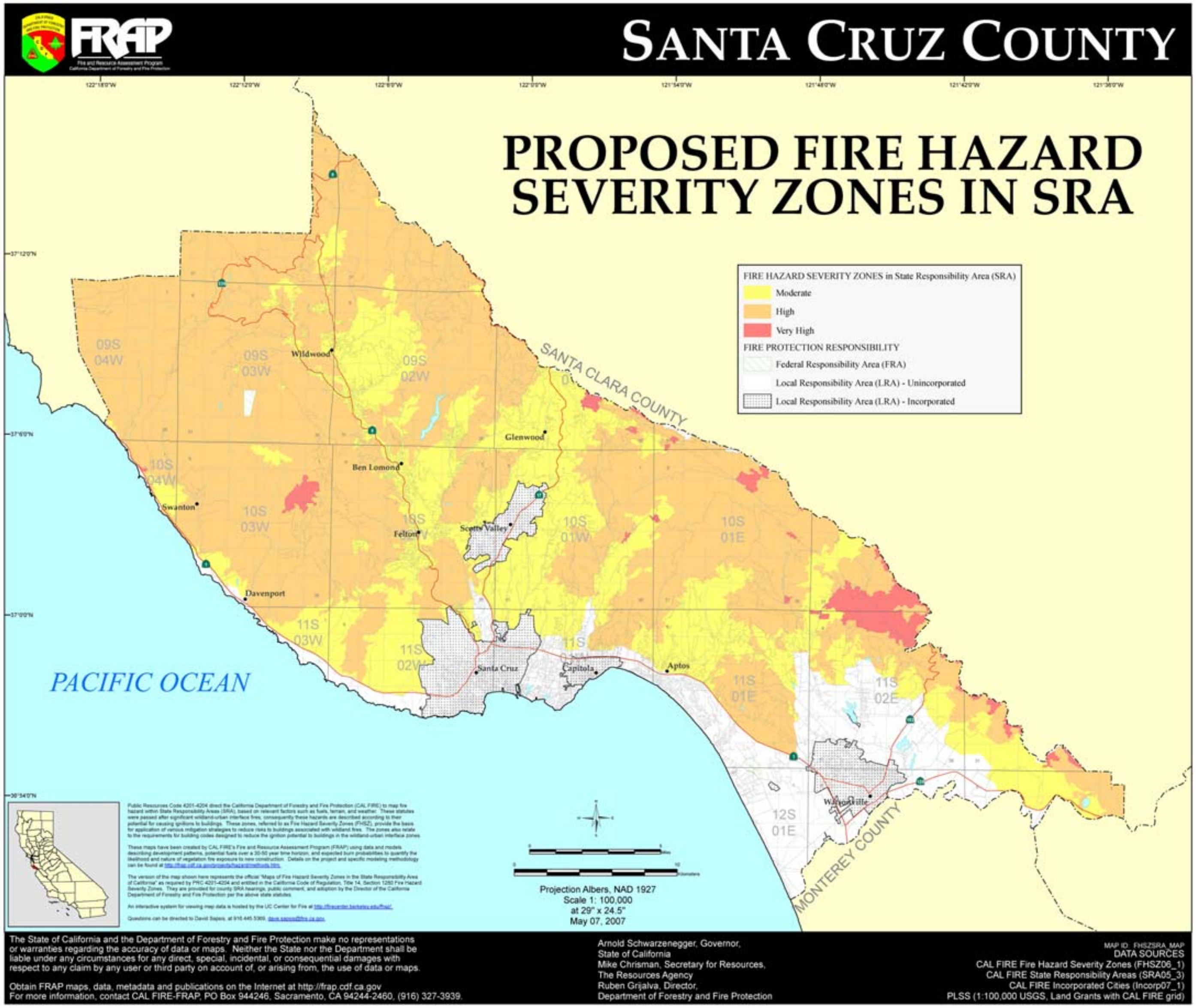
5.6.1 Sources of ignition

Lightning ignitions are infrequent in the Santa Cruz Mountains (Greenlee and Langenheim 1990). Probability of a human ignition may be substantial on the City of Santa Cruz watershed lands, especially with increased human recreational use (Swanson et al. (2002).

District lands where recreational access and trespass occur, such as the Olympia watershed, may be more vulnerable to fire ignition, especially areas invaded by French broom (Moore, 2007; personal communication).

Swanson et al. (2002) found it far more likely that a fire would ignite outside City of Santa Cruz watershed lands, and then spread to city lands. With modern fire suppression, most fires are contained at a small size so that large fires are improbable. Weather conditions will infrequently reach their optimum for supporting wildland fire. When an ignition occurs during these conditions, fuels characteristics and suppression efforts have little impact on large fire dynamics (Moritz, 1997).

Figure 5.1 Cal Fire's proposed fire hazard severity zones for Santa Cruz County.



Omi (2006) found the fire hazard assessment of a 1,000 acre proposed NTMP (non-industrial timber management plan) upstream of Lexington Reservoir to be misguided because it focused on fire hazard in the redwood stands in the harvest area instead of the more flammable chaparral within the Los Gatos Creek watershed.

> The potential for long-term damage to watershed values is arguably much greater in the chaparral zones than in the redwood stands within the NTMP. Notwithstanding the commercial value of redwood stumpage, the fire risk analysis should focus instead on the vegetation types comprising the entire upper watershed rather than the trees within the NTMP. The report is misleading insofar as it builds an apparent rationale for timber harvest under the guise of wildfire hazard reduction (Omi, 2006).

5.6.2 Weather conditions leading to increased fire hazard

Weather data are needed to identify thresholds in fire hazard and appropriate responses. It would be beneficial to know daily weather conditions (e.g., temperature, wind speeds, and humidity) that could generate fire conditions too intense for effective suppression, if an ignition were to occur (Moritz, 1997). The District can collect and monitor these data during fire season.

The conditions leading up to the 1959 fire in Newell Creek included a relatively wet winter, followed by an early dry-out period in spring/summer. These circumstances resulted in an early fire season, starting with unusually high biomass accumulation and very low fuel moistures.

Swanson Hydrology and Geomorphology (2002) found that the most significant fire hazard on the City of Santa Cruz watershed lands were located near the southeast corner of the Newell Creek parcel, bordering on the community of Lompico:

> Just over the ridge from Lompico is a U-shaped ravine extending down to Loch Lomond. If fire were to run up this ravine under extreme weather conditions, convection-driven flames could crest the ridge with concentrated energy. In firefighting lexicon, this topographic effect is called a ‘chimney.’ The 1959 fire started near this area where the Loch Lomond Dam was being constructed, but it did not spread into the community of Lompico. Under circumstances of offshore winds and/or more extreme fire weather, the outcome may have been different (Swanson et al., 2002).

The following account of the 1985 Lexington Fire came from the Santa Clara County Fire Department website (2007) provides another example of the importance of weather conditions in assessing fire hazard:

On Sunday, 7 July 1985, the Lexington Fire was reported to be burning about a quarter of an acre on the southeast side of Lexington Reservoir between the boat ramp and Soda Springs Road. Brush Patrol 3 and Engine 3 were first on the scene. The companies stretched hose lines up both sides of the fire in an effort to control the blaze. But, because of the terrain, wind and high temperatures, the fire was soon out of control. There was concern in the early hours of the fire that it would blown north through the canyon and into downtown Los Gatos, but this disaster was averted. The Lexington Fire continued to burn in a southeasterly direction despite all efforts to halt its progress. Throughout the next week, local firefighters and those from around the state battled night and day to control the blaze that consumed 14,000 acres, 42 homes, and caused the evacuation of 4,500 people and approximately $7 million in damage. After days of hard work, little rest, and constant danger to personnel, the fire was stopped at Loma Prieta Road off Summit Road. Fortunately, there was no loss of human life.

Historical data indicates that the Lexington wildfire spread primarily within the various chaparral patches and the ground fuels within the coast redwood and Douglas fir stands rather than the mature tree crowns. Untreated natural fuels, as demonstrated by the Lexington Fire, are also known to support wildland fire intensity and spread. However, the principal carrier of fire was the large tracts of native brush (chaparral), the dead and dying broken tree tops from a prior year heavy snow storm and the various dead and live ground fuels (brush, tree saplings and poles) lying beneath the mature tree stands (Montague, 2006).

5.6.3 Increased hazard from Sudden Oak Death and invasive species

Swanson et al. (2002) reported additional increases in dead fuels on the City of Santa Cruz watershed lands, due to the death of tanoak and coast live oak from *Phytophthora ramorum, a* disease that is widespread in the Santa Cruz Mountains. French broom (*Genista monspessulana*) infestations are quite flammable, increasing the risk of high intensity fire where it is present. This exotic shrub typically invades after a disturbance, such as logging or road-building, and flourishes in the disturbed understory of forests in the Santa Cruz Mountains. Where it flourishes, French broom increases fuel continuity into the canopy. It accumulates biomass more rapidly than native shrubs and exacerbates fuel loading. The District's watershed lands have not been surveyed for fire hazard, for Sudden Oak Death, or for invasive species such as French broom.

5.7 Water utility fire management plans

Many of the region's larger public water utilities that own thousands of acres of watershed property have extensive vegetation management or fire management plans (Marin Municipal Water District 1994, East Bay Municipal Utilities District 2000, and San Francisco Public Utilities District 2002). These plans assess the risk of fire, identify likely ignition sources, spell out fuel reduction practices, and describe emergency response procedures.

The City of Santa Cruz Water Department (SCWD) has an active fire management plan which involves annual coordination with CalFire – to ensure that Calfire has current maps, understands which roads are open, and that keys to gates have been issued. SCWD maintains fuel breaks on its property annually, and continuously maintains its watershed road system. SCWD also patrols these roads and maintains gates routinely to limit potential ignition sources, and to provide access to CalFire should they need it. Under severe conditions, SCWD prohibits all public access to its property (Berry, 2008).

The District routinely maintains the road system on District-owned watershed lands. While performing this maintenance, consultants routinely advise the District of any high fuel hazard areas where fire may be of special concern. The District operations staff knows the location of emergency access points throughout the watershed.

The District has not completely mapped its road system, emergency access points, or fire-fighting emergency fuel breaks and facilities. While emergency response procedures are generally defined for District operations, there is no formalized fire management plan.

5.8 Modeling fire

Models such as FARSITE (Finney, 1998 as cited by Swanson et al., 2002) can simulate fire spread and estimate fire intensity, flame lengths and spotting. The effects of suppression activities and fuel breaks can be incorporated into modeling scenarios, and likely ignition locations can be predicted. The city of Santa Cruz performed a cursory evaluation of fire hazard with respect to human lives and structures, and Swanson et al (2002) strongly recommended further evaluation.

Fried, Torn, and Mills (2004) estimated the impact of climatic change on wildland fire and suppression effectiveness in northern California by linking general circulation model output to local weather and fire records and projecting fire outcomes with an initial-attack suppression model. The warmer and windier conditions corresponding to a doubling of carbon in the atmosphere) climate scenario produced fires that burned more intensely and spread faster in most locations. Under this scenario, despite enhancement of fire suppression efforts, the number of escaped fires (those exceeding initial containment limits) increased 51% in the South San Francisco Bay area, 125% in the Sierra Nevada, and did not change on the north coast. Changes in area burned by contained fires were 41%, 41% and –8%, respectively. When interpolated to most of northern California's wildlands, these results translate to an average annual increase of 114 escapes (a doubling of the current frequency) and an additional 5,000 hectares (a 50% increase) burned by contained fires. On average, the fire return intervals in grass and brush vegetation types were cut in half. The estimates reported represent a *minimum* expected change, or best-case forecast. In addition to the increased suppression costs and economic damages, changes in fire severity of this magnitude would have widespread impacts on vegetation distribution, forest condition, and carbon storage, and greatly increase the risk to property, natural resources and human life. For more information about the potential impacts of climate change, refer to Chapter 7, Local Climate Change Assessment.

ACKNOWLEDGMENTS: CHAPTER 5

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CHAPTER 6: CULTURAL, HISTORICAL, RECREATIONAL AND EDUCATIONAL RESOURCES

6.0 Introduction

This chapter summarizes the existing cultural, historical, recreational, and educational resources of the San Lorenzo River watershed, with an emphasis on District-owned land. It should be noted that climate change could affect the resources discussed in this chapter. For example, impacts from unauthorized recreational use on District property could be exacerbated by the more extreme weather patterns, including longer droughts and more intense rainfall. These changes would likely increase erosion and compaction in disturbed areas.

6.1 Cultural and historical resources in the San Lorenzo River watershed

This section begins with an overview of the cultural and historical resources of the San Lorenzo River watershed, and ends with a similar overview of the District's ownership.

Big Basin State Park provides a sampling of the rich and varied cultural history of the watershed, from pre-historic Native American sites, homesteading and logging sites, to the many 1930s Civilian Conservation Corps park improvements. Ohlone hunting and gathering nomadic settlements were followed by the influx of Spanish missionaries, and again by waves of fortune-seekers of the California Gold Rush. The Spanish constructed Mission Santa Cruz, and introduced cattle-grazing and European farming techniques. The Gold Rush settlers introduced major extractive industries to the area, including logging and mining. Historical evidence from these previous land uses is still very much evident today.

6.1.1 Ohlone history and archeology

Swanson Hydrology & Geomorphology (2001) summarized pre-historical evidence in the area for the City of Santa Cruz Watershed Management Plan. Archaeological evidence suggests that Native Americans may have lived in the Santa Cruz area for 10,000 years or more. One site, with a flake scatter and two mortars, lies just to the northwest of the Newell Creek tract.

For the inhabitants of the central coast and mountains, gathering of terrestrial plant materials (e.g., seeds, acorns, tubers, and marine vegetation), collecting of shellfish, and hunting terrestrial and aquatic animals (e.g., deer, elk, rabbit, bear, seal, sea lion, fish, etc.) provided an abundance of resources for food, ornamentation, tools, and economic exchange. It is also clear that patterns of adaptation varied from place to place and changed through time.

The first residents of the San Lorenzo River watershed were the Ohlone Indians. Their numbers were small and their population density low. They hunted deer and other games, fished, and gathered various plant foods. They were nomadic; they traveled from place to place seasonally, following seasonal food sources. The Ohlone Indians were the original inhabitants of the canyon that now holds Loch Lomond Reservoir. This local group was referred to as the Zayante. They had enough acorns, fish, and small game to live a peaceful, easy life. Temascals (saunas), songs, and games were the rule, while fighting and thievery the exception (City of Santa Cruz Water Department, 2007).

They sometimes set fires in the grasslands, to encourage the growth of seed-bearing annuals and to facilitate hunting. Yet overall, their impact on the environment was extremely light, compared to the impact of today's residents.

6.1.2 Land-use history of the watershed

In many ways, the history of post-Ohlone land use in the San Lorenzo Valley watershed has created the conditions and landmarks of the current day. Three land-uses in particular have changed the landscape: Logging, agriculture, and mining.

6.1.2.a Landmarks of past of logging

The area is scattered with remains of old sawmills, steam donkeys, and old-growth stumps. Logging began in the 1830s but did not have a major impact until the 1860s. From the 1860s through the 1890s, logging was the major land use in the San Lorenzo River watershed. In 1864, 28 sawmills were operating in the Big Basin/San Lorenzo Valley area. By 1899, Boulder Creek was the fifth largest shipper of timber in the country. Early-day logging techniques were very hard on the environment. Clear-cutting was common, including hardwoods, such as madrones and tanoaks. Madrone was burned for charcoal, while bark from tanoaks was used for the tanning industry. After hardwoods were cut, the conifers were cut, and then fires were set. Initially, a fire was set to clear the bark from the logs and to clear shrubs to facilitate log removal. After logs were removed by ox teams, another fire was set, and it would burn uncontrolled into surrounding areas. This sequence of fires killed sprouts and saplings, allowed invasion of shrubs, and delayed natural reforestation. Burning, together with extreme soil erosion, could alter the land enough to prevent forest re-growth. In other areas the forest could re-grow only after a long natural successional sequence of brush to woodland to forest.

These large-scale disturbances to terrestrial plant and animal life also severely impacted fisheries. Transporting logs to mills accelerated erosion. Workers laid out pole roads in stream bottoms or drainage swales, with no attempt to control erosion. Gullies of these early-day operations are still visible throughout the watershed. Landslides and slumps were often precipitated by these logging practices, especially when skid trails following canyon bottoms undercut steep banks. Many of today's mapped landslide deposits probably date from this period.

6.1.2.b Landmarks of past mining

Throughout the watershed, old limekilns provide historical evidence of a once thriving industry. Figure 6.1 shows the Holmes limekilns in Felton.

Figure 6.1 The Holmes Limekilns in Felton

Photo courtesy of SCCRCD, 2007

The Holmes limekilns pictured above are located in Felton, and are registered as a historic resource by the county.

The mineral resources of the San Lorenzo River watershed are limited to primarily lime, limestone, sand, gravel, and crushed rock. Lime burning was one of the earliest industries in the watershed. Lime mining began in Spanish colonial times (USGS, UCSC Campus, 2007). Davis and Jordan began producing lime in 1853. By 1878, the County supplied more than one-third of the state's lime production, and most lime came from the San Lorenzo River watershed. Lime quarries were primarily located in the Felton and Santa Cruz areas. At one time, at least nine different kilns were in operation.

Prior to the development of the railroad system through the western United States, the only source of lime for cement construction in the Pacific Basin was the limestone quarries in the Santa Cruz area. Lime extracted locally was used in the construction of the Panama Canal, the Grand Coulee Dam, and in the reconstruction of San Francisco after the 1906 earthquake. Charcoal made by burning forest wood throughout the Santa Cruz Mountains fueled the limekilns that processed the lime. Lime was then hauled to ships for transport. By the early 1930s nearly all mines in the Santa Cruz area closed, as less expensive inland sources became available by rail. "Marble and granitic aggregate are still actively being mined in the Watsonville and Davenport areas. The marble and granitic rocks are part of the Salinian Basement Complex (Cretaceous and older) exposed through Ben Lomond Mountain" (US Geological Survey, UCSC Campus Report, 2007).

Limestone quarry operations altered the landscape and streams. The quarries increased turbidity, and kilns were fueled with native redwoods and shrubs. By 1943, only two limestone companies were still in existence. Today, none are functioning. Limestone quarrying continues outside the San Lorenzo River watershed; most notably by the cement plant in the Liddell Creek drainage.

Petroleum was never successfully developed in Santa Cruz County. Historically, oil seeps were known from at least two locations along the San Lorenzo River. The discovery of oil in Moody Gulch near Alma, Santa Clara County, in the 1870s, led to exploration in the San Lorenzo River watershed. Many unsuccessful wildcat wells were dug. In the Bear Creek drainage some of the abandoned wells (probably dating from the 1930s and 1940s) were not properly capped off, and today are discharging saline water into upper layer groundwater aquifers (San Lorenzo River Watershed Planning Process, 1976, as cited by Santa Cruz Public Library, 2007).

The Santa Margarita Sandstone is a geologic formation of loosely consolidated sands that are exceptionally well-suited for glass manufacturing and construction purposes. Mining of crushed rock, sand, and gravel for the construction industry began in the 1920s and 1930s. Mining continues today with four active quarries being located within the watershed. Only one rock quarry operation currently exists, and it is located on the east slope of Ben Lomond Mountain, where it prepares granite for construction purposes (San Lorenzo River Watershed Planning Process, 1976, as cited by Santa Cruz Public Library, 2007).

6.1.3 History of the District and District-owned lands

This section outlines the history of the District's formation and land acquisition within the larger historical context of the San Lorenzo River watershed.

With regards to pre-historic Ohlone settlements, no archeological sites on District-owned land have been observed by District staff. Furthermore, no such sites were found by an archeological survey completed in 1993, as part of a proposed timber harvest plan for the Malosky Creek property, now owned by the district.

As the San Lorenzo Valley was settled in the mid-1800s, populations in Ben Lomond, Brookdale and Boulder Creek formed their own water systems. Timber magnate H. L. Middleton formed the Boulder Creek Water Company (Brown, 2006). The flume that supplied water to residents from Boulder Creek also supplied hydro-electric power to run the local lumber mill and light up the town (Capebianco, 1991; Brown, 2006). Figure 6.2 is an old photograph taken of the flume in Boulder Creek.

Figure 6.2 Flume in the San Lorenzo Valley circa 1870

Photo courtesy SCCRCD, 2007

As vacation homes increased in the early 1900s, many small subdivisions developed their own water systems. These water systems were designed to serve the needs of Bay Area residents who occupied their vacation homes only a few weeks a year. Nearby springs and creeks supplied these water systems through flumes or pipelines. Santa Cruz County population more than doubled from 1900 to 1940, increasing from 21,512 to 45,057 (U.S. Census). As more people moved into the valley, the existing water systems became inadequate (Capebianco, 1991). Many residents recalled the Fourth of July and Labor Day with no water.

Frequent droughts between 1912 and 1939 convinced valley leaders to form a water district to better control water, to serve the needs of the valley (Capebianco, 1991). After one failed attempt to form a county water district by election in 1939, the San Lorenzo Valley County Water District was formed by the voters on April 3, 1941. Negative voter returns from the towns of Felton and Scotts Valley left those areas out of the district boundaries, which included Bear Creek, Boulder Creek, Alba, and Ben Lomond school districts, and part of the Sequoia school district (Brown, 2006).

After securing unclaimed water rights in Newell Creek and Bear Creek in 1942, the District's engineer presented a water master plan to the District board. The plan included storage dams on Boulder, Newell, and Bear creeks, and the upper San Lorenzo River. In 1945, voters failed to approve the $300,000 bond proposed to pay for the Boulder Creek dam. Shortly after, however, the District bought the 1,400 acre Waterman Gap property in the upper San Lorenzo River from Mrs. Edith Smith. The purchase price was $20/per acre for a total of $28,000 (Brown, 2006).

When the District again proposed a bond measure to the voters to fund the construction of a dam at Waterman Gap, a citizen group organized to oppose it, warning about a previous disaster in Johnstown Pennsylvania, where a dam broke after a flood, resulting in hundreds of people drowning (Brown, 2006). The citizen group also opposed the proposed dam at Newell Creek.

The bond measure was defeated in December 1946 (Brown, 2006). Still optimistic about building a dam, the District purchased the 3,400 acre Newell Creek property from Wells Fargo Bank, trustee to the deceased landowner, for the price of $18/acre or $60,000 (Brown, 2006).

Following the 1946 bond measure defeat, the District sold many oil-exploration leases on the Waterman Gap property to Texaco, Humble, Richfield and Union oil companies, but none of the test holes paid off. The leases did net the District enough by 1957 to offset the costs of purchasing both the Waterman Gap and Newell Creek properties (Brown, 2006).

While the District held steadfast to its plan of damming Newell Creek, it also pursued another path: purchasing additional water supplies. In 1954, the District offered Citizens Utilities Corporation $400,000 for their San Lorenzo Valley system (Brown, 2006).

In 1957, a $950,000 bond issue proposed by the District for purchase of Citizen Utilities and a Newell Creek dam project was approved by the voters. The District continued negotiating with Citizens Utilities, and also approached the City of Santa Cruz about partnering in constructing a dam on Newell Creek. Negotiations with Citizens Utilities failed, but the City of Santa Cruz agreed to partner with the District in building the Newell Creek dam in 1958 (Brown, 2006).

In 1959, the District signed an agreement with the City of Santa Cruz, in which the District sold the city its timber and mineral rights to the Newell Creek watershed, in exchange for 1/8 of the water rights. The city proceeded to dam Newell Creek, completing Loch Lomond dam in 1959. The agreement left the District's bond revenues of $950,000 untouched.

In 1961, the District began eminent domain proceedings to acquire Citizens Utilities of Felton, and an additional bond measure of $500,000 was approved by the voters for that purpose (Brown, 2006).

Citizens Utilities fought the buyout, but after three years, a settlement was reached. In 1965, the District agreed to buy all of Citizens Utilities holdings in Ben Lomond and Boulder Creek for $1.7 million, but the settlement excluded Citizens Utilities Felton water system. To make up the difference of $200,000 the District sold the last of its Newell Creek holdings to an investor group in San Jose (Brown, 2006).

In 1964, the District purchased an additional 600 acres of land at Waterman Gap (Brown, 2006).

In 1978, the District received a grant from the EPA to purchase the 200-acre Olympia watershed property, on which the District drilled the Olympia 1 well (Capebianco, 1991).

1985, the District began planning its 5-mile pipeline on Ben Lomond Mountain (Capebianco, 1991).

In 2000, the District sold its 1,400 acre Waterman Gap holdings to Sempervirens Fund, for the sum of $10.9 million, with the understanding that the land would be transferred to Castle Rock State Park. The District had given up plans to build a dam there. Furthermore, the District had no surface water sources downstream of the property. After receiving the proceeds from the Waterman Gap property, the District purchased the 206-acre Hulse-Cook property, between Malosky and Clear Creeks, which does have value as watershed.

In 2006, the District purchased the 188-acre Malosky Creek watershed property from Sempervirens Fund for $1.75 million. Sempervirens had previously purchased this property from timber owner Roger Burch. This was a key property for two reasons. First, the District's 5-mile pipeline runs across it. Second, the property connects the District's major watershed holdings to the north and south.

In 2008, the District purchased the Felton Water System from California-American water for $10.5 million, at the behest of the Felton community. The purchase was the result of a settlement following a long eminent-domain court battle initiated by the District. Legal costs and the purchase was largely funded by an $11 million bond measure known as "Measure W," which was approved with a 74.8% majority by the voters of Felton in 2005. The settlement included 252 acres of forested watershed property in the Fall Creek watershed, adjacent to Fall Creek State Park, which supplies the Felton water system with spring and surface water.

6.2 Recreational resources

This section provides an overview of the recreational resources within the San Lorenzo River watershed, followed by an overview of the recreational resources on District-owned lands.

6.2.1 History of tourism and recreation in the San Lorenzo River watershed

Tourism became a growing industry for the watershed early in the 1900s. The first state park was Big Basin, formed in 1906. Since the early 1960s State Parks have expanded to encompass over 9,000 acres of land in the watershed. In the early 1900s summer homes and communities were built to enjoy the area. Many of these homes and communities were built quite close to streams. Not only was the riparian area impinged upon by development, but dams and beaches were also constructed for summer recreation. With the growing number of homes came an increase in roads. The San Lorenzo River watershed was dominated by summer and second homes through the 1950s.

Historically, the tourist industry focused on the redwoods of the San Lorenzo Valley, and the beach at Santa Cruz.

The earliest redwood resort in the watershed was Big Tree Grove, near Felton, which opened in 1867. The South Pacific Coast Railroad which completed a mountain line from San Jose and points north to Santa Cruz in 1880, enabled residents from San Francisco and Oakland to make one-day picnic trips to the San Lorenzo Valley. The line's stop at Big Trees was a popular destination. The Santa Cruz beach had previously been available to the San Francisco Bay Area by a railway line from Gilroy to Watsonville to Santa Cruz completed in 1876. The South Pacific Coast Railroad line cut several hours off the round trip travel time.

The opening of Big Basin Redwoods State Park in 1904 attracted visitors to the San Lorenzo Valley, since Boulder Creek served as the gateway. In 1974-75 Big Basin attracted more than a half million visitors. Two other state parks now exist within the watershed boundary; Castle Rock State Park, near the northern drainage divide, and Henry Cowell Redwoods State Park near Felton. Henry Cowell State Park was formed in 1954 by the joining of Big Trees Groves with land donated by the Cowell family. In 1972, additional land surrounding Fall Creek was added to the Park.

6.2.2 Present day tourism and recreational opportunities in the watershed

The State Park System provides thousands of acres of the land-based recreation opportunities in the watershed. There are also many smaller county parks throughout the San Lorenzo Valley.

6.2.2.a State Parks

Major state parks include Henry Cowell and Fall Creek, Castle Rock, and Big Basin.

- ***Henry Cowell State Park,*** located in Felton, includes the Fall Creek unit. It features 15 miles of hiking and riding trails through a forest that looks nearly the same as it did 200 years ago. Zayante Indians once lived in the area, where they found shelter, water and game. The park is the home of the Redwood Grove, once known as Felton Big Trees, and features a self-guided nature path, Douglas fir, madrone, oak and a stand of Ponderosa pine. There is a picnic area next to the San Lorenzo River. The park has a nature center and bookstore. Adjoining the park is Roaring Camp Railroad, offering visitors a chance to journey back in time on an old steam locomotive. The main park area, featuring large, old-growth redwoods is approximately 1,750 acres, and the northern area (Fall Creek) is approximately 2,390 acres, with about 20 miles of hiking trails. The tallest tree in the park is approximately 285 feet tall and 16 feet wide. The oldest trees in the park are approximately 1,400 to 1,800 years old (California Department of Parks and Recreation, 2007).

- ***Castle Rock State Park,*** located in the extreme upper portion of the watershed with access off Skyline Boulevard, is a treasure of diversity and wilderness that is seldom seen next to a large metropolitan area. Ranging in elevation from a peak of 3,820 feet near Mt. Bielawski (Mt. McPhersen) to a low of 960 feet along the San Lorenzo River, Castle Rock State Park contains numerous plant communities including redwood forest, chaparral, grassland, riparian, and mixed hard wood forest. Steep canyons are sprinkled with unusual rock formations that are popular with rock climbers. The park is crisscrossed by 32 miles of hiking and horseback riding trails. These trails are part of a more extensive trail system that links the

Santa Clara and San Lorenzo valleys with Castle Rock State Park, Big Basin Redwoods State Park and the Pacific Coast (California Department of Parks and Recreation, 2007).

- ***Big Basin Redwoods State Park***, located northwest of Boulder Creek, is the oldest state park in California. The land was preserved in 1900 by Sempervirens Club, and transferred to the state in 1902. Home to the most impressive virgin redwood grove south of San Francisco, the park has miles of trails that link Big Basin to Castle Rock State Park and the eastern reaches of the Santa Cruz range. The Skyline-to-the-Sea Trail threads its way through the park along Waddell Creek to the beach and adjacent Theodore J. Hoover Natural Preserve, a freshwater marsh. The park features the beautiful Berry Creek waterfalls, and a wide variety of environments, from lush canyon bottoms to sparse chaparral-covered slopes (California Department of Parks and Recreation, 2007)

6.2.2.b County Parks

There are 743 existing acres Santa Cruz County Parks and Recreation facilities within the San Lorenzo Valley, as shown in Figure 2.2.

- Miller County Park at Kings Creek, consists of 410 acres of forested land, donated to the County by Save the Redwoods League, which purchased it from UC Santa Cruz. The park includes eighty acres of old-growth redwood forest.
- Quail Hollow Ranch County Park consists of 300 acres, noted for its unique sandhill habitat. The park is home to several rare and endangered plants and animals, including the Ben Lomond spineflower. It has numerous hiking trails, a historic ranch house, and a small pond.
- Felton Covered Bridge Community Park consists of 6.3 acres, and includes play areas, a picnic area, a sand volley ball court, turf and landscaping.
- Highlands County Park in Ben Lomond consists of 26 acres, and features playing fields, picnic areas, tennis courts, a senior center and the children's center of San Lorenzo Valley.
- The Ben Lomond Dam Park is a one acre neighborhood park where a dam is set up in the river during the summer.

6.2.2.c City parks

Other publicly-operated recreation areas located in the watershed are San Lorenzo City Park, DeLaveaga Park, Ben Lomond Park, San Lorenzo Valley Park, Harvey West Park, Boulder Creek Park, and Loch Lomond Recreation area.

6.2.3 Recreation outside of the park system

The watershed contains several golf courses, tennis/swim clubs, and privately-owned tourist attractions.

Fishing attracts visitors, especially the steelhead season which runs for approximately 3 ½ months in the fall and winter. The San Lorenzo River supports the only major coastal steelhead fishery south of the Russian River, but the Department of Fish and Game allows only catch-and-release fishing of steelhead in the river, and there are further restrictions (California Department of Fish and Game, 2007).

Recreational opportunities along the river include hiking, sunbathing, swimming, nature study, and wildlife observation. Facilities to enhance swimming conditions ranged from simple, makeshift rock dams to more elaborate wood dams, used by youth camps and recreational districts to create impoundments for boating, swimming, or fishing. California Department of Fish and Game records disclose seven of these large recreational dams along the mainstem of the San Lorenzo River. Swimming in the San Lorenzo River, at certain places, and during certain times of the year, has been curtailed due to the presence of coliform bacteria at dangerously high levels. (San Lorenzo River Watershed Planning Process, 1976 cited by Santa Cruz Public Library, 2007).

6.2.4 Recreation on District-owned lands

The District currently does not actively manage any of its lands for recreational purposes. For years, the District has had a written agreement with the Santa Cruz County Horseman's Association (SCCHA) for limited use of the District's Olympia property, on marked trails, and with permission. This agreement calls for an annual joint inspection of the property, including the entire trail network. This inspection has not occurred regularly in recent years.

The District has not marked or mapped trails authorized for use by the SCCHA, nor has it revisited the terms of the agreement with the SCCHA requiring trail maintenance.

6.2.4.a Trespass and its impacts on rare habitat

The District has worked to minimize trespass and off-road use of District watershed lands. Still there is evidence of frequent, unauthorized off-road vehicle and equestrian use on the Olympia property. Fences have been cut, and some roads and trails have eroded badly due to this unauthorized use. The District has in the past contracted with First Alarm to patrol watershed lands for trespass. Additional fencing and blocking of access with appropriate horse crossings may be necessary to protect the Olympia property, on the ridge trail, and adjacent to the old Olympia quarry.

The District has not fully assessed the impacts to biotic resources of recreational use on District lands.

The most easily accessible of the District's lands for recreation is the Olympia property, a site of the rare and endangered sandhills communities, endemic to Santa Cruz County. All sandhills sites in the county, including the Olympia property, receive some level of use for one or more types of recreation including: hiking/walking, horse riding, mountain biking, and off highway vehicle (OHV) riding. In addition, several sandhills habitat patches, especially those featuring rock outcrops, sand parkland ridges, or other promontories, have served as congregation sites for local youths. Finally, abandoned and active sand quarries are used as arenas for parties, paint ball wars, target shooting, and OHV riding (McGraw, 2004).

According to McGraw (2004):

> One of the most important points that must be considered in managing recreation in the sandhills is that the unique geology, soil, and biology of the sandhills, combined with their rarity, renders them especially susceptible to degradation by recreational use. Land managers and policy makers experienced in recreation management in other systems are

oftentimes unaware that sandhills communities can be greatly impacted by the same recreational use that would cause less of an impact to other systems (e.g. Redwood forest, Mixed Evergreen Forest). The inordinate impacts of recreation in the sandhills, when compared to other systems, are due primarily to three main factors: sandhills soils are fragile, sandhills species inhabit open areas where recreation occurs, and sandhills species and communities are extraordinarily rare. These same factors contribute to the differences in recreation impacts within sandhills habitat due to the heterogeneity of different communities.

6.2.4.b Potential benefits of limited recreational uses

Despite the many known negative impacts of current recreational use on sandhills habitat, recreation can also provide benefits for conservation of this rare habitat. Recreation can increase awareness and appreciation of sandhills communities, which can in turn facilitate conservation support and action on behalf of the sandhills. Public support of conservation efforts is crucial to many conservation and management efforts. People are more likely to support conservation efforts if they appreciate the habitat, and this appreciation most often results from personal experience. Outdoor recreation provides a mechanism for many to experience the sandhills (McGraw, 2004), and it may serve to increase support for the overall goals of conservation (McGraw, 2004; Herbert, 2007).

Land managers may also consider allowing recreation access to sandhills habitat, despite its negative effects on sandhills species and communities: Recreation may be part of their mission statement or mandate (McGraw, 2004). They may simply want to be 'good neighbors' to those who have enjoyed access to habitat historically. Limited recreation may provide maximum benefit to the public while reducing negative impacts to sandhills communities and species. Regulations governing endangered species (California and Federal Endangered Species Acts), and environmental impacts (California Environmental Quality Act) may limit the potential for recreational activities.

6.2.4.c Liability

The District prohibits all unauthorized access to its watershed lands. All persons must be in possession of a current permit from the District Administration office to enter District lands.

The District has not mapped and analyzed potentially hazardous areas on its lands, such as sites of toxics or hazardous wastes, dangerous cliffs, erosion prone soils, mine shafts, pipelines, and overhead power lines.

6.3 Educational resources

This section provides an overview of the educational resources within the San Lorenzo River watershed, followed by an overview of the educational resources on District-owned lands.

6.3.1 Educational resources in the San Lorenzo River watershed

This section lists and summarizes some of the educational resources available to residents of the watershed.

6.3.1.a The Santa Cruz County Public Libraries

- Since 1917, the Santa Cruz County Public libraries have provided materials and services to help residents throughout the county meet their personal, educational, cultural, and professional information needs. Its various branches provide free information services to all residents of the county, including the unincorporated areas of the San Lorenzo Valley. The library system has a website that provides a searchable database on local history (Santa Cruz Public Libraries, 2007).

6.3.1.b The Boulder Creek Historical Society

The Boulder Creek Historical Society was formed in 1976 to preserve the history of the San Lorenzo Valley by collecting and exhibiting artifacts, gathering historical information, and providing education through the San Lorenzo Valley Museum and its educational outreach programs (Boulder Creek Historical Society, 2007). The museum is located in Boulder Creek, and is open to the public. Among its exhibits are local logging history, the history of the Women's Christian Temperance Union of Boulder Creek, and a World War I exhibit featuring local soldiers.

6.3.1.c Roaring Camp Railroad

Roaring Camp Railroad, located in Felton, is a privately owned railroad that provides passenger service over trestles, through redwood groves and up a winding narrow-gauge grade to the summit of Bear Mountain. Dating from 1890, the locomotives are among the oldest and most authentically preserved narrow-gauge steam engines in the country, providing regularly scheduled passenger service (Roaring Camp Railroads, 2007). In the 1880s, narrow-gauge steam locomotives were used to haul giant redwood logs out of the mountains.

6.3.1.d The Santa Cruz County Science Fair program

The County Science Fair Program is coordinated through the Santa Cruz County Office of Education, provides support for young explorers and scientists. The annual event is a collaboration of students utilizing the scientific method to investigate and gather facts, science teachers, fair coordinators, mentors, and families (Santa Cruz County Office of Education, 2007).

6.3.1.e The California Regional Environmental Education Community (CREEC)

encourages environmental literacy of students throughout the state. The organization's website provides a searchable on-line directory of environmental resources, including environment-based education, field trips, curriculum, classes, and workshops aligned with state standards (CREEC, 2007).

6.3.1.f San Lorenzo Valley High School Watershed Academy

This four-year program for students in grades 9 through 12 offers four years of science, with specialty courses in aquaculture, environmental monitoring and environmental science. The Watershed Academy is a partnership between business and education that provides real-world work experience in the field, integrated academic and technical curriculum. The District has funded several projects of the Watershed Academy, including weather stations, ruggedized laptops, and lab equipment.

6.3.1.g Monterey Bay Salmon and Trout Project

This nonprofit environmental organization is dedicated to the restoration, conservation, and enhancement of native wild coho salmon and steelhead populations and their coastal and marine habitats from San Mateo to the south Monterey Bay area (Monterey Bay Salmon and Trout Project, 2007). Its Salmon & Trout Education Program (STEP) has been developed to provide students with a chance to learn "hands on" about salmon and steelhead and the habitats in which they live. The K-12 program uses a thematic firsthand approach, offering teachers the tools and the ideas for integrating math, science, language, arts, etc. Students learn about salmon and steelhead life cycles, their habitat requirements and the problems and solutions to preserving these "indicator" species and the watersheds in which they live (STEP, 2007). Teachers who wish to learn and participate in teaching STEP are offered a two-day workshop, which provides cooperative learning, utilizing actual lessons from the curriculum material.

6.3.1.h The California Native Plant Society (CNPS)

This statewide non-profit organization of amateurs and professionals with a common interest in California's native plants. CNPS seeks to increase understanding and appreciation of California's native plants and to preserve them in their natural habitat through scientific activities, education, and conservation (CNPS, 2007). The local Santa Cruz Chapter has focused work in the San Lorenzo River watershed. For example, in 2005, the chapter prepared a classroom slideshow for the SLV High School Watershed Academy, entitled, "An Introduction to Riparian Hydrology and Vegetation Sampling in the Rare and Unique Plant Communities of the San Lorenzo Valley Watershed: A Conservation Approach". The slideshow taught students about riparian plant communities and their value to wildlife and relationship to watershed hydrology. It also aimed to increase understanding of the value of undeveloped watershed lands and the value of riparian plant communities to fisheries, wildlife and water quality. The District funded this educational presentation through its education grant program.

6.3.1.i Santa Cruz County Resource Conservation District

This independent special district, formed to help people protect, conserve, and restore natural resources through information, education, and technical assistance programs (SCCRCD, 2007). The SCCRCD sponsors a rural roads program, and a manure management program. The SCCRCD's Watershed Cruzin' program is a teacher-training program in Santa Cruz County which provides a watershed activity guide for local classrooms and field trips. The guide facilitates fourth through twelfth grade teachers in helping students explore their local watersheds, using twenty-five classroom and field-based activities. Students discover where they live in their watershed, what else lives there, how healthy watersheds work. The District funded teacher workshops based on the Watershed Cruzin' curriculum in 2006-07.

6.3.1.j Valley Women's Club

This nonprofit is dedicated to community action, awareness and leadership in environmental, educational, social, and political concerns which affect the health and welfare of the San Lorenzo Valley and its community. The Education Committee provides scholarships for SLV High School graduates attending Cabrillo College. The Environmental Committee works to protect the watershed and to educate the public on forestry issues, erosion control, hazardous waste, recycling and other issues. It also monitors government policies and procedures.

6.3.1.k "Our Water Works in Santa Cruz County"

This activity book about the fresh water resources of Santa Cruz County is produced and funded in 2007 by the Soquel Creek Water District, the City of Watsonville Public Works and Utilities Department, and the City Santa Cruz Water Department. The District also provided financial support, and has distributed the activity book to local schools.

6.3.1.l Sandhills Alliance for Natural Diversity (SAND)

Based in Boulder Creek, this alliance was formed to preserve the rare and unique habitat of the Santa Cruz Sandhills, and inspire its stewardship through scientific research, public education, and integrated land use planning (SAND, 2007). Participants come from a variety of backgrounds and include Sandhills property owners, biologists, planners, educators, and other concerned citizens. Participants help preserve Sandhills habitat, host community educational programs, conduct scientific research, and help direct management for Sandhills habitat. SAND advises on many types of sandhills related projects, providing science-based information for successful conservation. In the spring, SAND leads guided wildflower walks to the sandhills. In 2006, the District funded SAND's project to create and install weatherproof educational signage for trails in sandhills habitat.

6.3.1.m The District's Education Grant Program

The District has sponsored local research, education and improvement projects in the watershed since 2003. The purpose of the program is to fund projects that enhance the understanding of the San Lorenzo River watershed environment or improve the watershed's environmental health. The District annually invites grant proposals from individuals, students, teachers, groups, and/or organizations. In 2007, the District's Educational Advisory Committee recommended that the District take a more proactive approach in soliciting proposals to study areas of known concern to the District. In 2009, the District offered applicants a series of projects to that would assist the District in filling some of the data gaps identified in this document.

6.3.2 Educational resources on District-owned lands

"Chapter 4: Biotic Resources," and "Appendix A: Fisheries," describe some of the valuable habitat and special status species present on District-owned lands. The District has supported research efforts on its lands with respect to fisheries and wildlife habitat. The District routinely grants permission to access its lands to researchers from the University of California, Santa Cruz.

The District has jointly funded salmonid research projects throughout the watershed, and has given NOAA Fisheries scientists access to its Zayante property. The District has also worked closely with the Sandhills Alliance for Natural Diversity to research and protect the sandhills communities on District-owned lands.

Recently, the District has authorized the Wildlands Restoration Team to access its watershed lands for the purpose of invasive species control and eradication.

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CHAPTER 7: LOCAL CLIMATE CHANGE ASSESSMENT

7.0 Introduction

Climate change is a relatively new and extremely significant issue for water resource management. Only recently has there been a political consensus acknowledging the overwhelming scientific evidence for the existence of climate change as well as the primary role of human activities as a contributing factor to climate change. This chapter begins with an overview of the evidence of global climate change due to recent increases in greenhouse gases (GHGs). It then discusses the two sides of climate change, mitigation and adaptation. It summarizes current scientific information about ongoing global climate change, in terms of general projections of large-scale climate change, and approaches of assessing climate change implications at the local scale. The chapter then outlines general climate change issues from the water resource management perspective, and identifies characteristics of the region to consider when assessing potential impacts, both primary and secondary, of climate change at the local scale. Finally, the chapter discusses the implications of climate change with regard to local forests and watersheds, the role of forests in climate change, and a discussion of the California Climate Action Registry and potential carbon credits for forestland owners.

7.1 Overview of the evidence for global climate change

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "any change in climate over time, whether due to natural variability or as a result of human activity" (IPCC, 2007). The energy balance of the earth's climate system is altered by changes in the atmospheric abundance of greenhouse gases and aerosols, solar radiation and land surface properties. The IPCC (2007) reported:

> Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentrations are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.

7.1.2 The greenhouse effect

Greenhouse gases (GHGs) affect climate by increasing the "greenhouse effect." As GHGs concentrate in the Earth's atmosphere, they trap heat by blocking part of the long-wave energy that the Earth normally radiates back to space; the resulting change in atmospheric energy balance affects both weather and climate (California Climate Action Registry, 2007).

7.1.3 Observed long-term changes

Scientists began measuring atmospheric CO_2 late in the nineteenth century. The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (IPCC, 2007). This increase is attributed to human activities, especially the burning of fossil fuels (coal, oil, natural gas) which have been locked within the earth's crust for millions of years, and the clearing and burning of forests. Huge swaths of temperate forests in the northern hemisphere were cleared for agriculture in the 19^{th} and early 20^{th} centuries. In recent decades, large areas of the Amazon rain forest have been cleared for agriculture and cattle grazing.

The IPCC (2007) documented an unequivocal warming of the climate system, evidenced by observed increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. The concentration of CO_2 in 2005 exceeded by far the natural range over the last 650,000 years, as determined from ice cores. The primary source of the increased CO_2 since 1750 results from fossil fuel use.

The carbon dioxide content of the atmosphere has steadily increased since the beginning of the industrial revolution. Samples of air, captured in core samples from the glacial ice of Greenland show no change in CO_2 content until about 300 years ago.

From 1850 to 1998, approximately 270 (+ 30) gigatons of carbon (GtC) have been emitted as carbon dioxide (CO_2) into the atmosphere from fossil fuel burning and cement production. About 136 (+ 55) GtC has been emitted as a result of land-use change, predominantly from forest ecosystems. This has led to an increase in the atmospheric content of carbon dioxide of 176 (+ 10) Gt C. Atmospheric concentrations increased from about 285 to 366 ppm (i.e., by ~28%), and about 43% of the total emissions over this time have been retained in the atmosphere. The remainder, about 230 (+ 60) Gt C, is estimated to have been taken up in approximately equal amounts in the oceans and the terrestrial ecosystems. Thus, on balance, the terrestrial ecosystems appear to have been a comparatively small net source of carbon dioxide during this period.

Observed long-term changes in climate include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (IPCC, 2007).

Other general observations include (IPCC, 2007):

- Widespread changes in extreme temperature have been observed over the last 50 years. Cold days and nights have become less frequent, while hot days, hot nights and heat waves have become more frequent.
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor.
- An average global temperature increase of approximately 1.4 degrees C has been observed in the last 50 years.

Despite the large increases in CO_2 in the atmosphere resulting from these activities, scientists have calculated that it is only about half of what they would expect from the amount of fossil fuel consumption and forest burning. There is some evidence that the missing CO_2 has been incorporated by increased growth of forests, especially in North America, and the increased amounts of phytoplankton in the oceans.

7.1.4 Abrupt climate change

Since publication of the 2007 IPCC report, the Climate Change Prediction Program of the U.S. Department of Energy's Office of Biological and Environmental Research (OBER) launched another study known as IMPACTS or Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions (U.S. Department of Energy, 2008).

IMPACTS is analyzing four factors that could hasten the “tipping point” toward irreversibility of global warming. These four factors include:

- Instability among marine ice sheets, particularly the West Antarctic ice sheet;
- Positive feedback mechanisms in subarctic forests and arctic ecosystems, leading to rapid methane release or large-scale changes in the surface energy balance;
- Destabilization of methane hydrates (vast deposits of methane gas caged in water ice), particularly in the Arctic Ocean; and
- Feedback between biosphere and atmosphere that could lead to megadroughts in North America.

The scientists will study these factors using a series of models, which they are building. The purpose is to predict more accurately how large-scale change may happen due to certain forcing mechanisms on a scale of years to decades, rather than centuries.

7.1.5 The carbon cycle

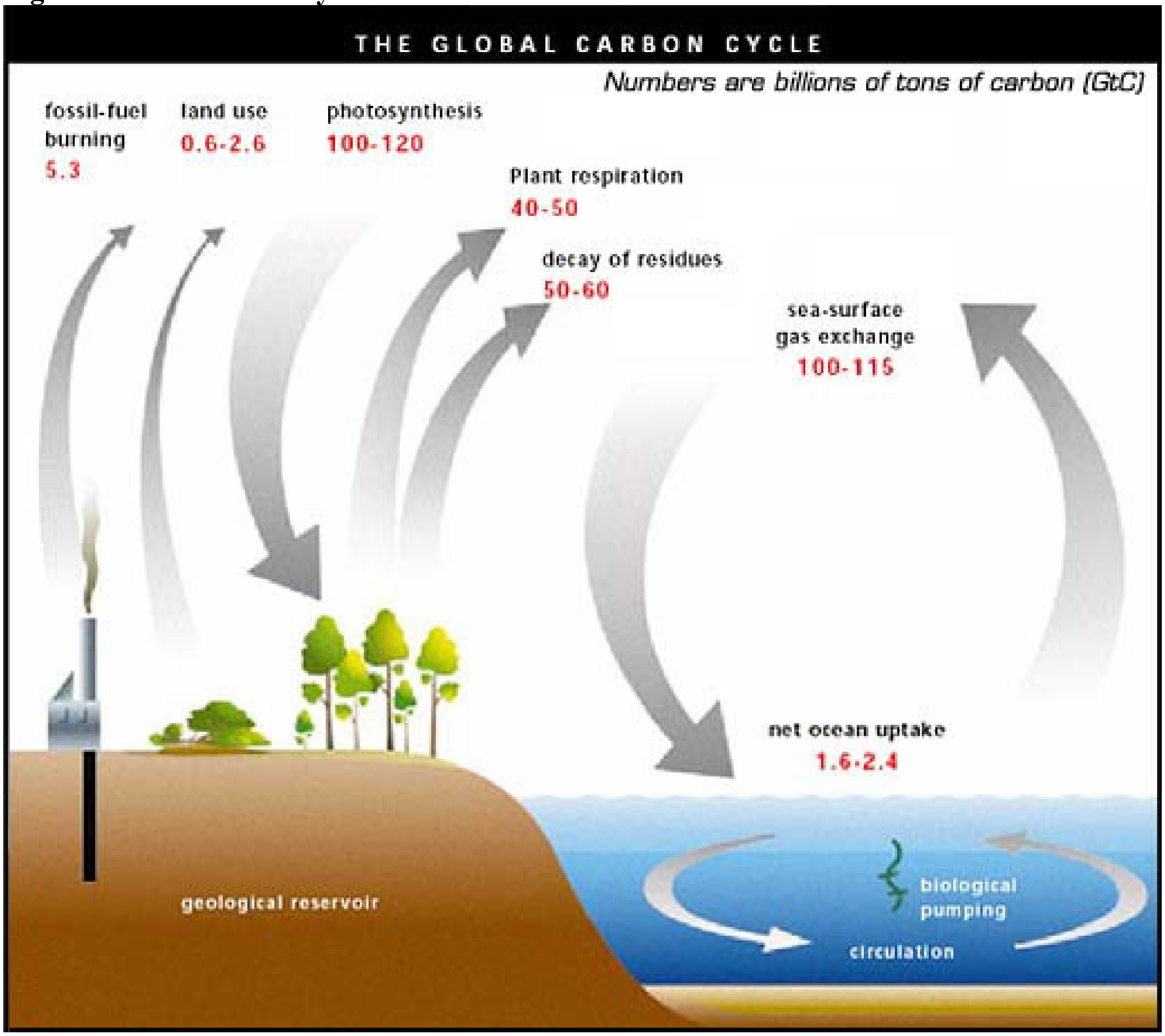
Carbon is an element found in all life forms, as well as in the atmosphere, the oceans, in minerals and fossil fuels stored in the earth’s crust. Just as there is a finite amount of water, which constantly moves through the hydrologic cycle, there is a finite amount of carbon, which moves through the carbon cycle. The carbon cycle works through a series of complex processes, including photosynthesis, respiration, combustion, and metabolism, as shown in Figure 7-1.

The Earth stores great quantities of carbon in the atmosphere, forests, soils, fossil fuels, and oceans. The earth’s reservoirs of carbon are found in the following major sinks:

- As organic molecules in living and dead organisms throughout the biosphere
- As the gas carbon dioxide in the atmosphere
- As organic matter in soils
- In the earth’s crust as fossil fuels and sedimentary rock deposits such as limestone, dolomite, and chalk
- In the oceans as dissolved atmospheric carbon dioxide and as calcium carbonate shells in marine organisms.

Although natural transfers of carbon dioxide are approximately 20 times greater than those due to human activity, they are in near balance, with the magnitude of carbon sources closely matching those of the sinks. The additional carbon resulting from human activity is the cause of the rise in atmospheric carbon dioxide concentration over the last 150 years.

Figure 7-1. The carbon cycle



Source: Oak Ridge National Laboratory

7.1.6 Restoring balance to the carbon cycle

Restoring balance to the global carbon cycle requires scaling back emissions of carbon dioxide into the atmosphere, and increasing carbon storage in natural carbon sinks.

Scaling back emissions primarily entails burning fewer fossil fuels. Slowing deforestation is another way to reduce emissions. When trees are cut and burned and the land converted to agriculture, the carbon stored in the forests and in the underlying soils is released to the atmosphere. This is estimated to be happening at roughly 1.6 gigaton (Gt) C/yr, producing an amount of carbon equal to approximately 20-25% of the total annual human-induced CO_2 emissions. Therefore, forest protection is a key component of any overall strategy to reduce atmospheric CO_2 concentrations.

Increasing carbon storage in natural carbon sinks can be done through land use change and forestry activities. When degraded lands are restored, carbon is removed from the atmosphere and stored in the biomass of trees through photosynthesis.

7.2 The two aspects of climate change: Mitigation and adaptation

Once the existence of climate change and its human causes are acknowledged, policy makers are left to address two looming aspects of climate change, mitigation and adaptation. Mitigation addresses the question, “How does society reduce its emissions of greenhouse gases to levels that will slow and eventually reverse the trend of global warming?” Scientific evidence suggests that policies with positive outcomes must be put into place shortly throughout the world in order to mitigate the levels of GHGs and to avert a global catastrophe. The other aspect of climate change, known as adaptation, addresses the question, “How does society prepare for the inevitable and increasing impacts to its citizens, its water resources, its infrastructure, and its natural landscapes?” The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as the “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC, 2007).

Clearly, both mitigation and adaptation must be addressed in tandem. No matter how successful society’s efforts are at reducing GHG emissions, levels are already so high in the atmosphere that the impacts of climate change will be with us for many generations (IPCC, 2007).

7.2.1 District planning to date for climate change mitigation and adaptation

In April 2008, the District initiated and co-sponsored with other local public water agencies a local forum entitled “Tools for Addressing Climate Change and Local Water Resources” (SLVWD et al., 2008). Internationally acclaimed water experts spoke at the forum to address the following questions:

1. What are the potential impacts of climate change on local water resources?
2. How can local water resource managers plan for these potential impacts?
3. How can local water agencies reduce their carbon footprints?

Shortly following this well-attended forum, the District Board of Directors approved a climate change resolution that commits the District to address both aspects of climate change, mitigation and adaptation. DVDs of the forum are available at county libraries and on request at the District office.

In terms of mitigation, the Board’s climate change resolution commits the District to reducing GHGs to levels defined in California law AB32. In compliance with the resolution, the District inventoried and reported in 2008 its greenhouse gas emissions for 2006 and 2007 to the California Climate Action Registry (CCAR). The CCAR accepted these reports in 2009, and the reports are publicly disclosed on CCAR website (CCAR, 2009). The inventory estimates the District’s total GHG emissions at 611 metric tons of CO_2e (CO_2 equivalents). The inventory itemizes GHG emissions by category and by facility. The report reveals that approximately 71% of the District’s total emissions can be attributed to indirect electricity, purchased from PG&E. The District’s primary use of electricity is from ground-water pumping. The report is a useful tool for the District to target the most efficient areas for reduction of GHGs throughout its operations.

In terms of adaptation, the Board’s climate change resolution also commits the District to addressing climate change in all planning documents in areas such as water conservation and demand management, watershed management, and water supply.

7.3 General projections of global climate change

Temperatures are projected to rise globally, although the projected temperature rise varies, depending on the model. The IPCC (2007) projects an average global warming of about 0.2 degrees C per decade for the next two decades. For the US, temperatures in the lower 48 states are projected to rise about 1/3 more than the global average (American Water Works Association, 2007). The IPCC (2007) projected the following general climate phenomena for the 21st century:

- Warmer and fewer cold days and nights over most land areas.
- Warmer and more frequent hot days and nights over most land areas.

The IPCC (2007) projected, as very likely, the following general climate phenomena for the 21st century:

- Warm spells/heat waves. Frequency increases over most land areas.
- Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas.

The IPCC (2007) projects a global mean sea level rise of up to 3.28 feet by 2100. More recent analyses estimate that sea level rise from warming oceans may be 1.4 meters (approximately 55 inches) over the next 100 years, or higher depending upon the rate at which glaciers and other ice sheets on land melt (San Francisco Bay Conservation and Development Commission, 2008),

7.4 General projections of climate change for California

In a literature review, Kiparsky and Gleick (2003) indicate that climate change will likely increase temperatures in California; increase climate variability, including storm intensity and drought frequency; raise sea level; and alter the effects of extreme events such as the El Niño/Southern Oscillation.

Snyder, Sloan, and Bell (2004) used a regional climate model to explore the potential impacts on the climate of California from increasing atmospheric CO_2 concentrations, from the perspective of the state's 10 hydrologic regions. They found that a doubling of CO_2 atmospheric conditions from pre-industrial values will lead to increased temperatures of up to 4 degrees C on an annual average basis, and of up to 5 degrees C on a monthly basis. Temperature increases were greatest in the central and northern regions. Precipitation results indicate drier winter for all regions, with a large reduction in precipitation from December to April and a smaller decrease from May to November. The result is a wet season that is slightly reduced in length. Their findings suggest that the total amount of water in the state will decrease, water needs will increase, and the timing of water availability will be greatly perturbed. Their results also indicate that the higher elevations tend to warm more rapidly than lower elevations (Snyder, Sloan and Bell, 2004).

According to the District's Water Supply Master Plan (Johnson, 2008; in progress), the following climatic conditions are predicted statewide for California:

- A 3 to 10°F temperature increase by 2100, with a greater proportion of this increase occurring in summer than in winter (Cayan et al., 2006).
- A continuation of mostly winter precipitation, virtually all from North Pacific winter storms. Precipitation may increase in winter while decreasing in spring (Cayan et al., 2006).

- Either relatively little change in overall precipitation statewide (Cayan et al., 2006) or a trend toward moderately decreased precipitation as indicated by a majority of model projections (California Department of Water Resources, 2006).
- A statewide reduction in average annual water availability of 27% and a resulting average annual reduction in water deliveries of 17 %, mainly due to changes in the nature, spatial distribution and timing of precipitation (e.g.; decreased snow pack; Medellin et al., March 2006).
- A relatively small increase in evapotranspiration, due to most of the temperature increase occurring at night (California Department of Water Resources, 2006).

Significant uncertainty remains about the nature and magnitude of potential climatic change in California (California Department of Water Resources, 2006).

7.5 Approaches of assessing climate change at the local scale

There are different approaches to assessing the implications for climate change at the local scale. The first is to downscale global climate models to the regional or local scale. The second is to use a hypothetical approach to assess local vulnerabilities to changes in rainfall and/or temperature (Gleick, 2007).

7.5.1 Downscaling from global climate models

While as many as 21 global climate models are in use, their practical use in downscaling climate projections to local areas is limited. Snyder et al. (2004) have developed a regional model for California that allows greater detail than is possible in global models, and that better describes the physical processes that occur at the local scale. While this model predicts average annual temperature increases everywhere in California, it predicts that the greatest average annual temperature increases will occur inland, with 2-3° F increase along the coast. Bell and Sloan (2006) predict more extreme climate events with a doubling of CO_2 conditions. This includes fewer rain days per year everywhere in the state, but with more intense rainfall in the spring, especially at higher elevations. Along with more concentrated rainfall, the risk of flooding is also predicted to increase (Bell and Sloan, 2006).

Throughout the state, regional models predict that total water availability will likely be reduced, with the timing of water delivery being disrupted, as the snow volume decreases and the rainy season is shortened. This scenario will likely result in increasing challenges to the storage and delivery of water throughout the state. As this happens, groundwater is expected to become increasingly important (Sloan, 2008).

Shortening of the water year is expected to increase fire potential, and to involve significant ecosystem impacts, so that conservation efforts will be more challenging (Sloan, 2008).

Yet, the prediction capability of even regional models is still uncertain, especially for coastal California, where the amount of precipitation depends on storm patterns off the Pacific Ocean. Storms may hit or miss the Santa Cruz Mountains, depending on unpredictable weather patterns.

7.5.2 Using localized hydrologic models

Hydrologic models capable of accepting hypothetical local rainfall and temperature data, to project outcomes in terms of streamflow and soil conditions, are useful for assessing vulnerabilities in different scenarios. However, such hydrologic models for the San Lorenzo River watershed are not currently available (Johnson, 2008; personal communication).

7.6 Adaptation: Climate change and water resource management

A U.S. government assessment (Gleick and Adams, 2000) of the potential consequences of climate change on U.S. water resources found that the country's water resources are seriously threatened by climate change.

To prepare for the impacts of climate change, Gleick (2008) urged water managers "to begin a systematic re-examination of engineering designs, operating rules, contingency plans, and water allocation policies."

According to the American Water Works Association (AWWA, 2007), higher temperatures and rising sea levels are likely to have several impacts on water resource management:

- Increased salinity in coastal aquifers and brackish surface water sources
- Increased risk of coastal flooding of water utility facilities
- Potential increases in coastal storm intensities

Where water utilities depend on snowpack for supply, there are further implications for water resource managers. Snowpack will be smaller and melt earlier, and this change will alter recharge of surface and groundwater sources. Santa Cruz County, like other coastal areas, will not be directly impacted by decreased snowpack .

Generally, far northern areas will likely be wetter, and far southern areas will likely be drier. Generally, winters are projected to be wetter, and summers are projected to be drier. Models also project that the eastern US will be wetter, while the plains and the western US will be drier. Beyond that, precipitation patterns are too complex to predict with any degree of certainty (AWWA, 2007).

A higher demand for water will likely result from more heat waves and dry days, coupled with more intense rainfall and runoff, with less infiltration. In addition, more intense rainfall and runoff could damage water infrastructure, such as intakes, pump stations, and treatment plants.

As precipitation is expected to occur in more intense periods, the increased run-off could potentially result in reduced groundwater recharge. This, in turn, could result in less groundwater storage and lower stream baseflows, both of which would impact the District and the entire watershed.

Changes in temperature and precipitation will change vegetation patterns in watersheds and recharge areas, which could lead to more sedimentation. Increased rainfall and runoff intensity could result in more sewage overflows, and upset the basis of stormwater management plans and TMDLs.

Increased temperature and sedimentation from more intense runoff could lead to eutrophication of source waters.

For more information about the potential impact of climate change on the District's water resources, refer to the District's Draft Water Supply Master Plan (Johnson, 2008; in progress).

7.7 Adaptation: Using climate change models to predict local vulnerabilities

The AWWA (2007) presented several case studies from around the country, showing how climate change models were downscaled to assess local vulnerabilities and prepare appropriate responses. These case studies demonstrate that impacts from climate change may have significant, and far-reaching impacts on water resources that may vary depending on local variables and conditions.

For example, the New York City (NYC) Department of Environmental Protection (DEP) used five global climate models (GCMs) and three IPCC emissions scenarios to downscale projections for the NYC watershed region. The NYC water system uses two large surface water sources, one of which is unfiltered. The DEP is concerned about ways in which climate change could impact water quality regulatory compliance, and how it could increase demand for water.

The DEP has three primary concerns about potential climate change impacts on water quality:

- Increased fecal coliform levels from migrating birds
- Increased number of turbidity events due to more intense rainfall
- Increased algal blooms in reservoirs due to more rainfall and temperature increases

First, if climate change impacts waterfowl migrations, fecal coliform levels from birds could increase. The DEP is tracking bird migrations and using microbiological fingerprinting to identify specific sources of fecal coliform in the watershed. Second, the DEP is concerned about a projected increased number of turbidity events resulting from more intense rainfall. The DEP plans on increasing turbidity monitoring throughout the watershed. Third, climate change could lead to increased algal blooms. Increased rainfall, nutrient loading, and temperature could lead to oxygen depletion, and taste, odor, and color problems. It could also increase fish kills, and disinfection by-products. In response to these concerns, the DEP installed tertiary treatment, and is developing a watershed program to control agricultural nutrient sources. It is also fine-tuning its chlorination process.

The New York City DEP is also concerned that more frequent droughts will cause demand to exceed supply. Anticipated impacts are enforcement of conservation restrictions, balance between water storage and flood control, and difficulty meeting temperature and flow requirements for stream releases. To address these concerns, the DEP is reducing demand through low-flow devices and metering, developing water re-use systems, and evaluating new sources.

7.8 Adaptation: Preparing for historic local extreme climate events

While large cities like New York may have the resources to downscale global climate models to estimate local impacts on their water resources, there are other efficient and less expensive approaches that small districts, such as San Lorenzo Valley Water District, can use. One such approach is to prepare for or adapt to climate change by assessing conditions documented in past extreme climate events and to incorporate practices to address these conditions, should they re-occur. For example, water conservation programs could be implemented earlier in the year to address a higher probability of drought. Likewise, erosion control practices could be implemented in areas of the watershed that are prone to erosion, in anticipation of more intense precipitation events.

According to Johnson (2008, in progress):

> The most significant expected result of climate change in California, reduced snow pack, will not directly impact coastal areas relying solely on local water supplies, such as Santa Cruz County. However, the central coast appears to be located near the boundary between

an increasingly dry south and a possibly wetter north. Furthermore, increased spring and summer temperatures will result in increased water demand.

Johnson (2008, in progress) summarized predictions about the local impacts of climate change:

• During the next 50 to 100 years in Santa Cruz County, temperatures will rise 8° to 9°F and rainfall will decrease by nearly half between February and April, and summers will be hotter with increased water demand, according to researchers from the UCSC Climate Change and Impacts Laboratory (Santa Cruz Sentinel, November 12, 2006).

• Although unlikely, the possibility of sudden climatic change exists as evidenced by extreme droughts apparent in extended records, occurring over large areas and several decades, possibly due to oscillating ocean conditions. Sudden cooling could be brought on by volcanic eruptions or other causes of atmospheric debris (CDWR, July 2006).

• The increased variability of annual rainfall over 10-year periods suggests a potentially greater frequency of extremely wet and/or dry years. Thus, even if little change in mean annual rainfall occurs, it may become more difficult to effectively capture and/or store the increased proportion of average rainfall that occurs during very wet years.

The increased variability also suggests a potentially reduced occurrence of extended droughts. For example, one of the lowest periods of historic variability occurred during the prolonged drought of 1917-1935.

7.9 Forests, climate change, and carbon sequestration

Climate change is altering forests both directly—from changing temperature and moisture—and indirectly— through shifting patterns of fire, insects, and disease.

At the same time, forests help to mitigate climate change. Forests absorb CO_2 from the atmosphere and store it in wood and forest soils. Forests also release CO_2 to the atmosphere whenever land is converted to non-forest uses, or when forests are logged, burned, or suffer from outbreaks of insects and disease.

All living forests both absorb and release CO_2. The relative balance between these two processes determines whether a forest is a source or sink of CO_2.

Climate scientists have identified the next few decades as a crucial period for avoiding potentially catastrophic changes in climate, so immediate changes in traditional forest management policies and practices are called for. Increased time between harvests is especially important, as old-growth forests store much more carbon than younger forests.

Increasing either the frequency or severity of disturbance will generally lower carbon stores. Annual carbon emissions in the U.S. from logging and wood processing exceed those from forest wildfires (Harmon and Krankina, 2008).

Carbon stores in wood products are released over time through decay at an average rate of 2% annually, according to Pacific Forest Trust (2007). The GHG emissions rate of wood products is similar to that of decaying wood in old-growth forests (Harmon and Krankina, 2008). Perhaps more importantly, the declining average age of harvest *rotations* (length of time between harvests) means that less carbon is being stored in forests than in the past, as older forests store more carbon than younger forests (Harmon and Krankina, 2008). While younger forests may, on average, grow at faster rates than older forests, older forests store significantly more carbon per acre than younger ones, and even old-growth forests continue to sequester carbon from the atmosphere (Luyssaert, et al., 2008).

7.9.1 Forests as carbon sinks

Because terrestrial ecological systems retain live biomass, decomposing organic matter and soil, they play an important role in the global carbon cycle. Carbon is exchanged naturally between these systems and the atmosphere through photosynthesis, respiration, decomposition, and combustion. Human activities change carbon stocks in these pools and exchanges between them and the atmosphere through land use, land-use change, and forestry, among other activities. Substantial amounts of carbon have been released from forest clearing at high and middle latitudes over the last several centuries, and in the tropics during the latter part of the 20th century.

Forests are natural sinks of carbon. There is carbon uptake into both vegetation and soils in terrestrial ecosystems, as shown in Table 7-1. Forests absorb carbon dioxide from the atmosphere and store it as carbon in their biomass. When forests are converted to other uses, the carbon stored in the forest biomass, is released into the atmosphere both immediately and over time (IPCC, Special Report on Land Use, 2007). Carbon emissions can also be avoided by conserving and/or protecting forests, as shown by the projects summarized in Table 7-2.

Table 7-1. Global carbon stocks in vegetation and soil carbon pools down to a depth of 1 m.

Biome	Area (10^9 ha)	Global Carbon Stocks (Gt C)		
		Vegetation	*Soil*	*Total*
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts and semideserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Croplands	1.60	3	128	131
Total	15.12	466	2 011	2 477

Note: There is considerable uncertainty in the numbers given, because of ambiguity of definitions of biomes, but the table still provides an overview of the magnitude of carbon stocks in terrestrial systems.

Source: IPCC Special Report on Land Use, Land-Use Change and Forestry, 2007.

Table 7-2. Emissions avoidance through conservation of existing stocks: Forest conservation-protection

Project and host country	Dominant activity	Project information[a]	Area (ha)	Estimated lifetime CO_2 benefits (000 t C)	Estimated CO_2 benefits per hectare (t C ha^{-1})[b]
Amazon Basin, AES/Oxfam, Ecuador, Bolivia, Peru	Protection, land tenure	1992; USA	1,500,000	15,000	10
Paraguay Forest Protection, AES, Paraguay	Protection	1992; USA	58,000	14,600	252
ECOLAND, Costa Rica	Protection	16; 1995; USA	2,500	366	146
Rio Bravo, Belize	Protection, forest management	40; 1994; USA	14,000 protection; 46,406 forest management	2,400	39
Noel Kempff, Bolivia	Protection from logging and deforestation	30; 1996; USA	~696,000	4,000-6,000	7
Protected Area Project, Costa Rica	Preservation via purchase and land title enhancement	25; 1997; USA	530,000	4,600-8,900	17
Virilla Basin Project, Costa Rica	Protection, reforestation	25; 1997; Norway	52,000	231	4
Subtotal Range (or Average)		*27*	*2,852,500*	*41,200-47,500*	*4-252*

[a] Project lifetime (in years); date initiated; investor country.

[b] Estimated CO_2 benefits per hectare and totals for projects are generally reported by project developers, do not use standardized or consistent GHG accounting methods, generally only report CO_2 (not other GHGs), and have not been independently reviewed. The wide range of estimates for conservation/protection projects results from the type of activity (e.g., avoided logging or avoided deforestation) and from a large project area with only a fraction affected by the activity per year

Source: IPCC Special Report on Land Use, Land-Use Change and Forestry: From Table 5-2: Overview of selected LULUCF AIJ pilot program and other projects, in at least early stages of implementation.

The US EPA acknowledges forest practices that affect greenhouse gases, as shown in Table 7-3.

Table 7-3. Forestry practices that sequester or preserve carbon

Key Forestry Practices	Typical definition and some examples	Effect on greenhouse gases
Afforestation	Tree planting on lands previously not in forestry (e.g., conversion of marginal cropland to trees).	Increases carbon storage through sequestration.
Reforestation	Tree planting on lands that in the more recent past were in forestry, excluding the planting of trees immediately after harvest (e.g., restoring trees on severely burned lands that will demonstrably not regenerate without intervention).	Increases carbon storage through sequestration.
Forest preservation or avoided deforestation	Protection of forests that are threatened by logging or clearing.	Avoids CO_2 emissions via conservation of existing carbon stocks.
Forest management	Modification to forestry practices that produce wood products to enhance sequestration over time (e.g., lengthening the harvest-regeneration cycle, adopting low-impact logging).	Increases carbon storage by sequestration and may also avoid CO_2 emissions by altering management. May generate some N_2O emissions due to fertilization practices.

Source: US EPA, 2006

Different approaches have been proposed to address the duration of projects in relation to their ability to increase carbon stocks and decrease greenhouse gas emissions. They should be maintained in perpetuity because their "reversal" at any point in time could invalidate a project; and (ii) they should be maintained until they counteract the effect of an equivalent amount of greenhouse gases emitted to the atmosphere (IPCC Special Report on Land Use, 2007).

Techniques and tools exist to measure carbon stocks in project areas relatively precisely depending on the carbon pool. However, the same level of precision for the climate change mitigation effects of the project may not be achievable because of difficulties in establishing baselines and due to leakage. Currently, there are no guidelines as to the level of precision to which pools should be measured and monitored. Precision and cost of measuring and monitoring are related. Preliminary limited data on measured and monitored relevant aboveground and below-ground carbon pools to precision levels of about 10% of the mean at a cost of about US$ 1–5 per hectare and US$ 0.10–0.50 per ton of carbon have been reported. Qualified independent third-party verification could play an essential role in ensuring unbiased monitoring (IPCC, Special Report on Land Use, 2007).

7.10 The California Climate Action Registry and carbon credits for forestland owners

California Assembly Bill 32 (AB 32), also known as the "California Global Warming Solutions Act of 2006," was the first law to comprehensively limit greenhouse gas (GHG) emissions at the state level. AB 32 was passed by Legislature, signed by the governor, and became law January 1,

2007. It established annual mandatory reporting of GHG emissions for significant sources and sets emission limits to cut the state's GHG emissions to 1990 levels by 2020.

California Senate Bill 527, enacted in 2001, provided for a voluntary, non-profit California Climate Action Registry (CCAR) to assist commercial and governmental entities that operate in the state to establish GHG emissions baselines. Any future GHG emission reduction requirements would apply against these baselines.

The CCAR is a non-profit public/private partnership that serves as a voluntary greenhouse gas (GHG) registry to protect, encourage, and promote early actions to reduce GHG emissions. The Registry provides consistent GHG reporting standards and tools for organizations to measure, report, certify, and reduce their GHG emissions in California and/or the U.S.

AB 32 requires that the California Air Resources Board incorporate the standards and protocols developed by the CCAR when developing the state's mandatory reporting program. CCAR members who have entered their carbon emissions to CCAR standards will have their data recognized and accepted by the state's future reporting program.

The purposes of the CCAR are as follows:

- To enable participating entities to voluntarily measure and record GHG emissions made after 1990 in an accurate manner and consistent format that is independently certified;
- To establish standards that facilitate the accurate, consistent, and transparent measurement and monitoring of GHG emissions;
- To help various entities establish emissions baselines against which any future federal GHG emissions reduction requirements may be applied;
- To encourage voluntary actions to increase energy efficiency and reduce GHG emissions;
- To ensure that participating organizations receive appropriate consideration for certified emissions results under any future state, federal or international regulatory regime relating to GHG emissions;
- To recognize, publicize, and promote participants in the Registry; and
- To recruit broad participation in the process (CCAR, 2007).

7.10.1 The Climate Registry

In 2008, the CCAR announced that it would begin transitioning into a national non-profit known as the Climate Registry, a nonprofit organization that provides meaningful information to reduce greenhouse gas emissions. The Climate Registry adopted many of the same policies and protocols of the CCAR, though it has not yet adopted the CCAR's forestry protocols. It establishes consistent, transparent standards throughout North America for businesses and governments to calculate, verify and publicly report their carbon footprints in a single, unified registry (The Climate Registry, 2009). Members of CCAR have been invited to join The Climate Registry.

7.10.2 CCAR Forest Protocols

The CCAR released draft protocols in December 2008 for landowners of at least 100 acres of forestland in California. At the time of this writing, the California Air Resources Board (CARB) was revising the CCAR protocols for final adoption by the state, but at the time of this writing, the final draft has not been released.

7.10.3 Carbon credits for forest landowners conserving forests

Note: The following discussion addresses CCAR's forest protocols which are being revised at the time of this writing for adoption by the CARB.

The CCAR protocols allow for forest-owning entities to account for and report the biological emissions and carbon stocks of their forests over time. Forest owners who are already members of CCAR, and who have reported their GHG emissions, can register forest projects to quantify and monitor GHG reductions, or net carbon sequestration, resulting from specific activities, such as reforestation, improved forest management practices, and avoided deforestation. The CCAR's Forest Project Protocols follow a set of principles and standards that ensure the rigor and legitimacy of the greenhouse gas emissions reduction credits generated by the project activity:

Principle one: Establish a baseline to compare measurable gains in against which to measure emissions reductions. This requires carbon experts to conduct a comprehensive inventory of carbon stores within the project area.

Principle two: Provide proof that the project's emission reductions are additional to what would have happened without the project existing.

For example, by preventing logging of a project area, as scheduled under a filed timber harvest plan, emissions from future logging operations are eliminated, and carbon sequestration is allowed to continue.

Principle three: Ensure the permanence of the project's carbon stores.

A permanent conservation easement on the project area legally establishes restrictions on specific carbon-emitting activities in perpetuity.

Principle four: Assure against leakage, or the occurrence of emissions elsewhere due to the project activity.

A forest landowner must have all of its land holdings assessed for carbon storage and emissions in order to ensure that the restricted carbon-emitting activity will not simply be displaced to other lands it owned, which would cancel out the benefits of the project.

Principle five: Obtain third-party certification of the Forest Project by Registry-approved Forest Certifier.

The Pacific Forest Trust (PFT) was the first land trust in California to purchase conservation easements to address the problem that US forestlands are a declining carbon sink and contribute significantly to the release of carbon dioxide into the atmosphere. PFT's conservation easements generally allow logging to continue, but at less aggressive levels than the State Forest Practice Rules allow.

Sempervirens Fund (2007) was the first land trust to establish a forest carbon project to exclusively embody the management goals of protection and preservation under the standards set forth by the CCAR. Sempervirens Fund entered into an agreement with Pacific Gas & Electric Company to sell 14 years of carbon credits to the utility as part of PG & E's Climate Smart Program (Sempervirens Fund, 2007) .In exchange, Sempervirens agreed to place a conservation easement on the 202-acre Lompico Headwaters project area, which permanently prevents all logging on the property and allows for the continued sequestration of carbon in perpetuity.

A forest carbon market would create the private financial incentive to conserve forests and reduce carbon loss. Such a carbon market would monetize carbon stored in forest biomass, as other carbon dioxide emission sectors would seek to meet their emission reduction goals through the purchase of emission offsets or carbon "credits" from land trusts and other entities that are able to provide these credits.

Private forest landowners could sell their forest carbon stores as credits to buyers and maintaining these forest carbon stores over time. Conservation easements would require forest landowners to keep their forests and grow them older before they are harvested.

To ensure the quality of carbon credits, a standardized carbon accounting system would use generally accepted accounting principles, including annual debits and credits, with adjustments for risk. Standardized rules would ensure that carbon credits developed in the U.S. are accepted in other carbon markets. These standardized rules would reflect the following characteristics, according to PFT (2007):

- Additionality: Carbon sequestration gains are calculated as *additional* to those that would have accrued from "business-as-usual" forest management, under the Forest Practice Rules. This assures net gains in forest carbon stores.

- Permanence: To earn credits in the carbon accounting system, forests must be managed for the *permanent* sequestration of carbon. This ensures that tons stored today are not released again and that forest loss is not simply delayed for a time. Hence, there must be a requirement for permanent deed restrictions or conservation easements.

- Verifiability: The forest carbon accounting system must be accurate and must ensure timely third-party *verification* of forest carbon gains and losses.

- Co-benefits: Forest carbon projects must avoid environmental harm and result in environmental and social co-benefits, such as habitat restoration, biodiversity enhancement, watershed protection and sustainable timber economies.

Conversion of natural forest ecosystems (or non-forest ecosystems like wetlands or grasslands) to forest plantations should not be eligible for credit.

PFT envisions that a forest carbon market would achieve multiple conservation co-benefits:

> As more forest is preserved and grows older, forest biodiversity is enhanced--making forests more resilient. In addition, older preserved forests provide habitat for endangered species and enhance water quality. Forest landowners would be encouraged to provide these additional conservation benefits if they received an economic benefit in return, and a carbon market can provide such dividends (PFT, 2007).

7.10.4 The District's forestland, carbon sequestration, and potential carbon credits

The District owns ≈ 1,800 acres of forest watershed, which is managed toward old-growth to maximize water quality. Carbon sequestration is a substantial co-benefit of these management practices, since large, old redwood trees sequester tons of carbon from the atmosphere. Now that the District has certified its GHG emissions with the CCAR, it may be eligible to use the carbon stores in its forests as carbon credits in future markets. In order to do so, the District would need to inventory the carbon stores in its forest lands, and have that inventory confirmed by a certified third party verifier.

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APPENDIX A: FISHERIES

A.0 Introduction

This chapter lists the fish species native to the San Lorenzo River, as well as non-native species, and describes the life histories of coho salmon and steelhead, the watershed's native anadromous salmonids. The chapter summarizes the ecological role of these salmonids, followed by a review of the decline of the species throughout their ranges, and within the San Lorenzo River watershed. It then describes major impacts that threaten the survival of coho and steelhead, and closes with a short summary of the National Marine Fisheries Service recovery plan for these species under the federal Endangered Species Act.

It should be noted that climate change will likely exacerbate the problems facing local salmonid fisheries addressed in this chapter. Altered hydrologic patterns may result in increased droughts and more intense rain events. For more information about these potential significant impacts, refer to Chapter 7: Local Climate Change Assessment.

The District has acted as a responsible resource manager, funding long-term steelhead monitoring and habitat evaluation. Figure A.1 and A.2 illustrate some of the District's projects.

Figure A.1. Sampling for steelhead in fastwater habitat of the San Lorenzo River

Collins 2007

Biologists sampling for steelhead in fastwater habitat during monitoring in San Lorenzo River (Henry Cowell Park) during a project funded by the District.

Figure A.2. Measuring and releasing juvenile steelhead in the San Lorenzo River

Collins 2007

Biologists measuring and releasing juvenile steelhead during monitoring in the San Lorenzo River (Henry Cowell Park) during a project funded by the District.

A.0.1 Native fishes

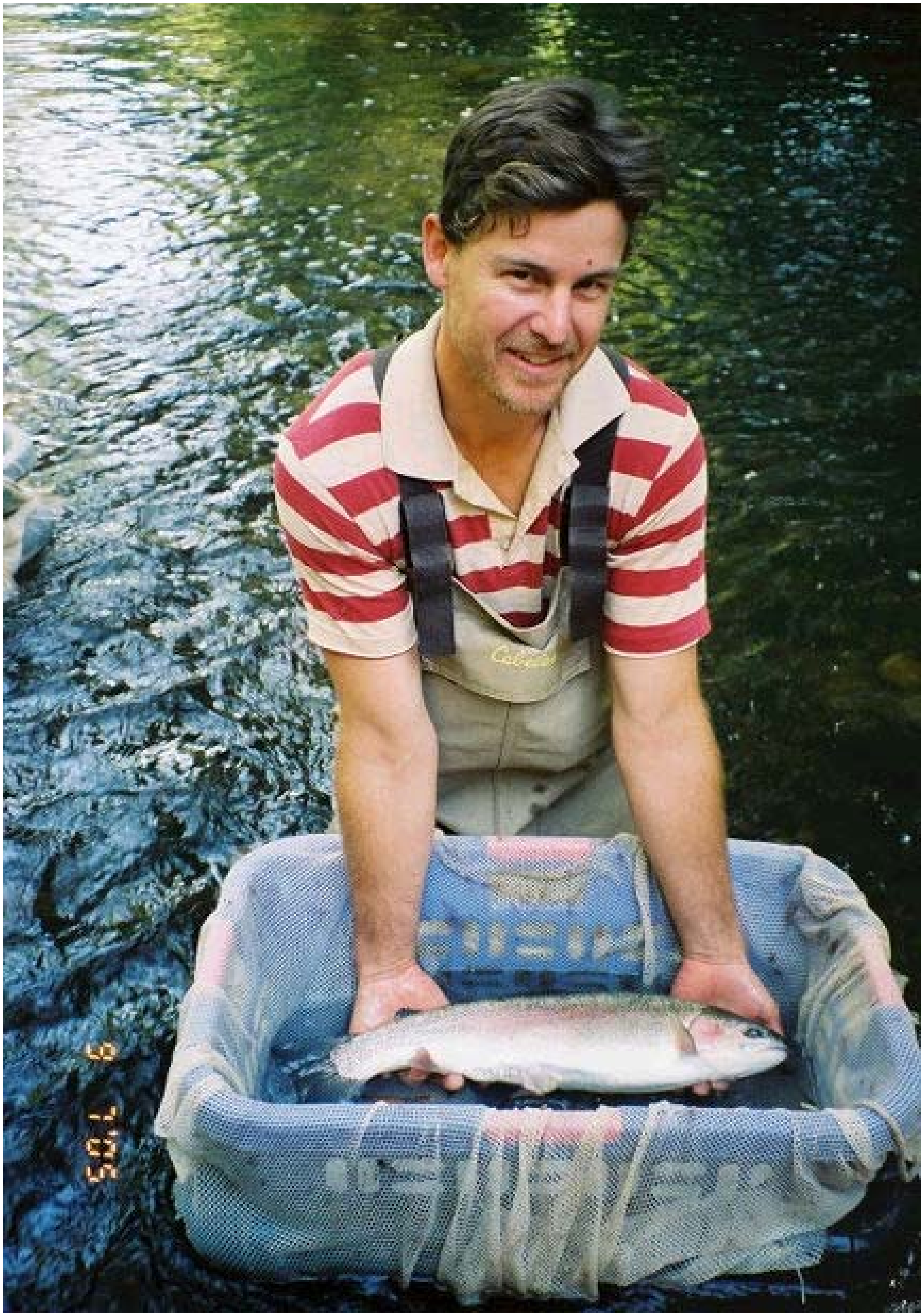
The San Lorenzo River and its estuary are inhabited by at least 25 different species of native fish. These include salmonids and other anadromous fish, which spend part of their lives in the ocean and part in freshwater. The anadromous species of recreational interest are steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). These salmonids live as juveniles in freshwater, spend their major growth and adult stages in the ocean, and return to spawn in their natal freshwater streams where they were originally hatched. Figure A.3 shows a spawning adult coho salmon. Figure A.4 shows a steelhead netted in the San Lorenzo River near Ben Lomond.

Figure A.3 Adult coho salmon spawning.

Anon. 2006

Adult Coho salmon on spawning grounds of Devil's Gulch Creek, a tributary to Lagunitas Creek.

Figure A.4. Adult steelhead netted in the middle mainstem near Ben Lomond



Alley 2005

The steelhead (*Oncorhynchus mykiss*) spend most of their adult life in the ocean, and return to spawn in freshwater streams where they were originally hatched.

Coho salmon and steelhead are the two species inhabiting the watershed upstream of the lagoon that are listed as threatened or endangered under State or Federal law, and are the only species whose populations have been monitored intensively. However, coho salmon rarely reproduce successfully any longer in the watershed. Young were detected in 2005, 24 years after their last sighting. However, a few stray adults from more northerly drainages have been recently measured and released at the Felton diversion dam in winter.

Other native fish living upstream of the lagoon/estuary include Pacific lamprey (*Lampetra tridentata*), threespine stickleback (*Gasterosteus aculeatus*), speckled dace (*Rhinichthys osculus*) pictured in A.4, coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*Cottus asper*), California roach (*Hesperoleucus symmetricus*), and Sacramento sucker (*Catostomus occidentalis*).

Figure A.5. Pacific lamprey from the San Lorenzo River

Alley 2005

The Pacific lamprey resembles an eel, and also spends its adult life in the ocean, migrating up coastal streams to spawn.

The Pacific lamprey, pictured in Figure A.5, is often mistakenly referred to as an eel. The Pacific lamprey is a 2-3 foot long, silver-gray to steel blue, snake-shaped fish that spends its adult life in the ocean and migrates up coastal streams to spawn. Adult Pacific lamprey can be seen in streams holding onto rocks with their suction mouths or moving rocks to build their nests in spring. The Pacific lamprey is parasitic in the ocean, but not when it spawns in freshwater streams. Juveniles are born eyeless, and remain so for the first part of their lives, as they burrow into the sands of streambeds. The range of the Pacific lamprey is similar to that of steelhead. The Pacific lamprey is locally extinct from areas of southern California.

Anadromous and resident populations of the threespine stickleback, pictured in Figure A.6, have a patchy distribution throughout the watershed (Smith, 1982).

Figure A.6. Threespine stickleback.

Courtesy Alley 2008

Threespine stickleback with males in bright breeding coloration.

Speckled dace, pictured in Figure A.7, and California roach, pictured in Figure A.8, inhabit primarily the mainstem and low gradient tributaries, with the California roach preferring, warmer and slower habitat.

Figure A.7. Speckled dace.

Reis 2006

Speckled Dace captured in the San Lorenzo River at Henry Cowell Park.

Figure A.8. California roach.

Collins 2007

California roach captured in the San Lorenzo River at Henry Cowell Park.

The Sacramento sucker, pictured in Figure A.9, inhabits areas with good pool development. Large adults generally inhabit the mainstem at the bottom of deep pools or congregate under large instream wood clusters. Juveniles and adults are ubiquitous throughout the watershed because they migrate upstream to spawn in spring and have wide environmental tolerances.

Figure A.9. Sacramento sucker.

Alley 1997

Adult Sacramento sucker with mouth extended.

The prickly sculpin, pictured in Figure A.10, primarily inhabits pools. The generally darker prickly sculpins inhabit primarily pools and generally grow larger than coastrange sculpins.

The coastrange sculpin, pictured in Figure A.11, inhabits pools and fastwater habitat (riffles and runs).

Sculpin hide during the day and feed actively at night, as observed by local biologists using starlight goggles (Alley, 2008). Few sculpin of either species are found above the steep San Lorenzo River gorge that flows through Henry Cowell State Park, or above the fish ladder at the Felton diversion dam, except in Newell Creek. Denil fish ladders, such as the one at the Felton water diversion dam, are impassable to sculpin, which migrate downstream as adults to spawn and move back upstream afterwards (Alley, 2008). Young Pacific staghorn sculpin, have been captured in the lagoon and immediately upstream in the flood control channel through Santa Cruz.

Figure A.10. Prickly sculpin

Alley 1997

Large prickly sculpin captured from a pool in Soquel Creek. The generally darker prickly sculpin inhabit primarily pools and generally grow larger than coastrange sculpin.

Figure A.11. Coastrange sculpin

Wheeler 2006

Colorful coastrange sculpin captured from a riffle in the San Lorenzo River at Henry Cowell Park.

A.0.2 Native estaurine fish species

When the sandbar at the river mouth is opened to the ocean by winter storms, the lagoon becomes an estuary, which is inhabited by numerous marine species. Common estuarine species include topsmelt (*Atherinops affinis*), staghorn sculpin (*Leptocottus armatus*), starry flounder (*Platichthys stellatus*) and shiner perch (*Cymatogaster aggregata*). The most notable freshwater species that also utilize the lagoon include steelhead, threespine stickleback, Sacramento sucker and tidewater goby (*Eucyclogobius newberryi*), a federally and state listed endangered species.

The tidewater goby resides only in the lagoon/estuary, where it squirts along the bottom to feed on small invertebrates. Males build nests in burrows in the sand, and the species requires good overwintering shelter and a closed summer sandbar to provide freshwater breeding areas in the lagoon.

A.0.3 Non-native fishes

Though non-native (artificially introduced) fishes pose a serious threat to native species in many regions, they have created little impact in the San Lorenzo River watershed. The non-natives that escape from Loch Lomond have difficulty surviving the large winter stormflows and are seldom found elsewhere in the watershed.

According to Smith (1982):

> The absence of non-native fishes and the variation in species compositions of the native fishes in different streams due to barriers, stream size, and habitat make Santa Cruz County streams ideal for studies on native fish ecology.

Non-native fish occasionally escape into Newell Creek from Loch Lomond where they were originally introduced. Golden shiners (*Notemigonus crysoleucas*) and bluegill (*Lepomis macrochirus*) have been captured in Newell Creek, downstream from the dam. Planted rainbow trout in the reservoir, distinguished by their larger size and different and brighter coloration, have also periodically washed over the dam into Newell Creek and have been captured during fall sampling. Green sunfish (*Lepomis cyanellus*) established a population in Carbonera Creek in the mid 1990s from ponds in Scotts Valley and are presumably still there. A large brown bullhead catfish (*Ictalurus nebulosus*) was observed in the San Lorenzo River near the mouth of Newell Creek in 2003 during a snorkel survey (D. Alley and K. Kittleson, personal observation). Another catfish was observed in the San Lorenzo River in Henry Cowell State Park during an earlier snorkeling survey (W. Heady, personal observation). A third catfish was caught during sampling in lower Carbonera Creek in 1981.

Steelhead and rainbow trout are the same species and interbreed, but steelhead are anadromous and rainbow trout are not; they remain in freshwater. A small percentage of steelhead remain in freshwater as rainbow trout. A small percentage of rainbow trout offspring migrate to the ocean to become steelhead. Ocean-run steelhead grow much faster, are larger as adults than rainbow trout and spawn many more eggs than resident rainbow. These characteristics make the steelhead life history more adapted to local conditions than the rainbow.

A.1. Life cycles and habitat requirements of salmonids

Figure A.12 depicts the life cycles of coho salmon and steelhead.

Figure A.12. Life cycles of coho salmon and steelhead.

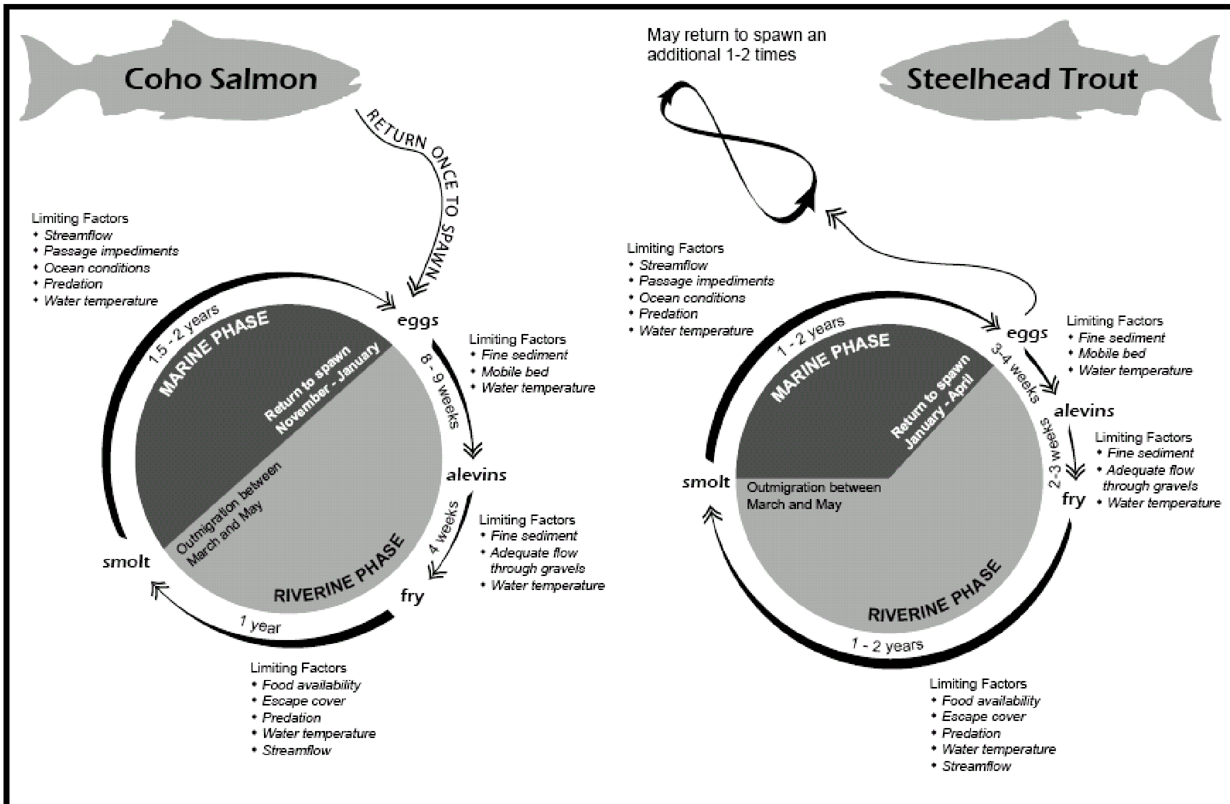


Figure 1.2: Life cycles of the Coho salmon and Steelhead trout showing duration of each stage and critical environmental factors affecting survival and reproduction. Coho salmon live for approximately 3 years before they spawn and die. Steelhead may live for up to 5 years and spawn as many as three times.

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Most adult steelhead migrate upstream from the ocean through an open sandbar after several prolonged storms; the migration seldom begins earlier than December and may extend into May if late spring storms develop. Adult fish may be blocked by natural barriers such as bedrock falls, wide and shallow riffles, and occasionally logjams. Man-made objects, such as culverts, bridge abutments and dams are often significant barriers. Some barriers may completely block upstream migration, but many barriers are passable at higher streamflows. Except in extreme cases, some adult steelhead can pass in most years, since they are capable of timing their upstream movement to match peak stormflow conditions. However, in drought years and years when storms are delayed, incomplete barriers can become serious temporary barriers to spawning steelhead and especially coho salmon, because coho spawn earlier than steelhead.

Coho salmon often have severe problems because their migration period, November through early February, often occurs prior to the stormflows needed to pass shallow riffles, boulder falls and partial logjam barriers. Access at the river mouth can be a problem due to failure of sandbar breaching during drought or delayed stormflow. In recent years, the rainfall pattern of early winter storms has allowed for good coho access to the San Lorenzo system.

Smolts (juvenile steelhead and coho salmon that have physiologically transformed in preparation for ocean life) tend to migrate downstream to the estuary and ocean in March through early June in local streams. In streams where lagoons, which are formed by a closed sandbar in the summer, young-of-the-year (YOY) and yearling fish may spend several months in this highly productive lagoon habitat and grow rapidly. For most local streams, downstream migration is a problem only under extreme drought conditions that cause reaches to dewater and/or the sandbar at the rivermouth to close prematurely before the smolts reach the Bay.

A.1.1 Spawning habitat requirements

Steelhead and coho salmon require spawning sites with gravels containing little sand and silt as well as good flows of clean water moving over and through them. The redds (nests) of all coho salmon and those steelhead that spawn earlier in the winter are more likely to be washed out or buried in fine sediment by succeeding winter storms.

Steelhead spawning success may be limited by scour from winter storms in some Santa Cruz County streams. Unless hatching success has been severely reduced, however, survival of eggs and alevins is usually sufficient to saturate the limited available rearing habitat in most small coastal streams and San Lorenzo tributaries. However, in the mainstem San Lorenzo River downstream of the Boulder Creek confluence, spawning success may be an important limiting factor. The production of YOY fish is related to spawning success, which is a function of the quality of spawning conditions, the pattern of storm events and ease of spawning access to upper reaches of tributaries, where spawning conditions are generally better.

A.1.2 YOY and smolt habitat requirements

In the mainstem San Lorenzo River below Boulder Creek, many steelhead require only one summer of residence before reaching smolt size. Except in streams with high summer flow volumes, steelhead require two summers of residence before reaching smolt size. This is the case for most juveniles inhabiting the upper mainstem above Boulder Creek and all tributaries of the San Lorenzo River. Juvenile steelhead are generally identified as YOY (first year) and yearlings (second year). The slow growth and often two-year residence time of most local juvenile steelhead indicate that the year class can be adversely affected by low streamflows or other problems during either of the two years of residence. Nearly all coho salmon, however, smolt after one year under most conditions, despite their smaller size. Because of their smaller size, juvenile coho salmon have lower survival than steelhead in the ocean.

Growth of YOY steelhead and coho salmon appears to be regulated by available insect food, although escape cover and pool, run and riffle depth are also important in regulating juvenile numbers, especially for larger fish. Aquatic insect production is maximized in unshaded, high gradient riffles dominated by relatively unembedded substrate larger than about 4 inches in diameter. Densities of yearling and smolt-sized steelhead in smaller stream channels, such as the upper San Lorenzo upstream of the Boulder Creek confluence and San Lorenzo tributaries, are usually regulated by water depth and the amount of escape cover during low-flow periods of the year (July-October). Deep habitat with maximum escape cover is best.

Yearling steelhead growth usually shows a large increase during the period of March through June when higher streamflow of sufficient clarity is available. Larger steelhead may smolt as yearlings in spring if they grow large enough. For steelhead that stay a second summer, summer growth is very slight in many tributaries (or even negative in terms of weight) as flow reductions eliminate fast-water feeding areas and reduce insect production. The "growth habitat" provided by higher flows in spring and fall (and in summer for the mainstem river) is very important, since ocean survival to adulthood increases exponentially with smolt size.

During summer in the mainstem San Lorenzo River downstream of the Boulder Creek confluence, steelhead use primarily fast-water habitat where insect drift is the greatest. This habitat is found in deeper riffles, heads of pools and faster runs. YOY and small yearling steelhead that have moved down from tributaries can grow very fast in this habitat if streamflows are high and sustained throughout the summer.

A.1.3 General habitat requirements for salmonids

Pools and step-runs are the primary habitat for steelhead in summer in San Lorenzo tributaries and the upper San Lorenzo River above the Boulder Creek confluence. Primary feeding habitat is at the heads of pools and in deeper pocket water of step-runs. The deeper the pools, the more value they have. Higher streamflow enhances food availability, surface turbulence and habitat depth, all factors in increasing steelhead densities and growth rates. Where found together, young steelhead use pools and faster water in riffles and runs/ step-runs, while coho salmon use primarily pools because of they are poorer swimmers.

Deeper pools, undercut banks, side channels, large unembedded rocks and large wood clusters provide shelter for fish against the high winter flows. In some years, such as 1982 and 1998, extreme floods may make overwintering habitat the critical limiting factor in steelhead production. In years when higher stormflows occur, these refuges are critical, and it is unknown how much refuge is actually needed. The remaining coho streams, such as Gazos Waddell and Scott creeks, have considerably more instream wood for winter refuge than streams where coho have been extirpated (Leicester, 2005).

A.1.4 Natural history of steelhead

Taxonomically, steelhead are grouped with other Pacific salmon. Their range varies historically. Steelhead have been caught along the continental shelf from Japan up through the Bering Sea and south to Baja California (Love, 1996). At sea, steelhead are most abundant between Oregon and the Gulf of Alaska, and may migrate up to 2,900 miles (Love, 1996). Historically, steelhead ranged as far south as the California-Mexico boarder, but their current southern limit is Malibu Creek in Los Angeles County (Alley et al., 2004a). Unfortunately, water extractions, dams, and prolonged drought have all but extirpated steelhead from their southern range. Steelhead spend one to two years in the ocean before returning to spawn. They can reach 45 inches in length and weigh more than 40 pounds (Love, 1996). However, the average fork length of returning adults captured at the Felton diversion dam is consistently between 28 and 29 inches (Terry Umsted, San Lorenzo Valley High School Teacher and Trap Supervisor, personal communication 2006), and weighing approximately 8-10 pounds.

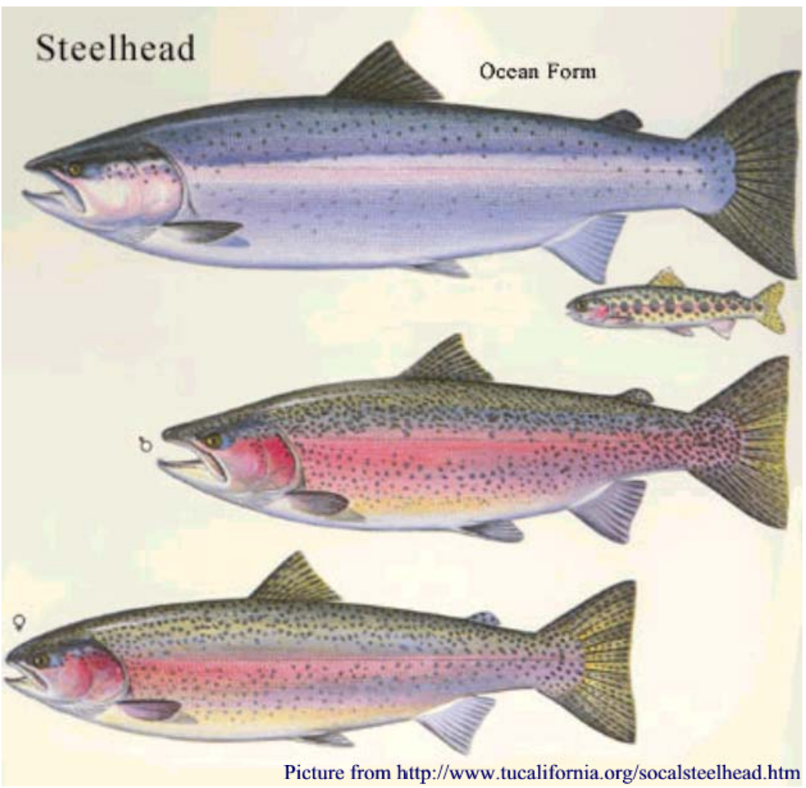
A.1.4.a Life span and survival rates

Steelhead rarely live longer than seven years. Four years is considered a typical lifespan in this region. Despite their fecundity, steelhead survival to spawning is very low. From their extensive research on Scott and Waddell Creeks, Shapovalov and Taft (1954) calculated survival rates from the egg to the adult’s first time returning to spawn. They termed this period primary overall survival. Between the years 1933 and 1938 they calculated primary over-all survival for steelhead in Waddell Creek to be between 0.017% and 0.029%.

A.1.4.b Spawning

Steelhead spawn in streams with coastal access along the Pacific Coast of North America. Steelhead differ from other salmon in their ability to return to sea after spawning and to return again to their natal stream to spawn in later years. Figure A.13 depicts the ocean and freshwater phases of steelhead. This ability has given steelhead the advantage of stronger spawning year classes in the face of annual variability in habitat quality in freshwater and the ocean. In any given year, the returning steelhead adults are from multiple years of previous spawning, unlike other salmon. This gives the steelhead population resilience and adaptability in a fluctuating environment. One or even two successive years of poor smolt production do not necessarily create long-term low numbers of returning adult steelhead in succeeding years.

Figure A.13. Ocean and freshwater phases of steelhead



In some rivers, male steelhead may migrate upstream first, waiting for females and determining a hierarchical ranking. Females create the nest, called a "redd," by turning on their side and slapping their tails on the bottom. This lifts the material into the water column. The lighter sand and silt is carried away by the current. The gravels bounce slightly downstream so that a pit is formed with a mound just downstream of it. A pair (male and female) then spawns in the pit. The female lays eggs while the male emits sperm. Steelhead produce an average of about 6,000 eggs per female, varying from 2,000 to 12,000 (Benkman, 1976; Love, 1996).

The hydraulics within the redd pit actually pull the eggs and sperm into the gravels of the streambed. Satellite males may attempt to swim in and emit their sperm during this time. After the eggs have been laid, the female moves upstream and repeats her digging to bury the fertilized eggs in gravel 8-14 inches thick. A pair or individuals may spawn several times. Females are more likely to survive to spawn multiple times and multiple years. There are usually more females than males at spawning grounds (Love, 1996). After spawning, if the adult has not died of old age, fatigue, disease or predation, it may swim back to the ocean and return to spawn the following year.

Redds are excavated at the tails of pools or glides just upstream of riffles. Steelhead prefer to spawn just upstream of steep, narrowing riffles to maximize the flow of oxygenated water through the interstitial spaces between gravel particles in the streambed. This provides a relatively shallow section with an even bottom of good gravels and enough streamflow to nurture the eggs and larvae. The female spawns in the deepest part of the stream cross-section to avoid dewatering of the nest. Steelhead require spawning beds of deep, loosely aggregated gravels with a minimum of fine sediments. Gravels in the range of 5 to 90 mm are optimal for salmonid spawning beds (Alley et al., 2004a; Alley, 2002). Steelhead may spawn over previously prepared redds of coho or other steelhead.

A.1.4.c Egg incubation and fry emergence

Warmer water decreases incubation time (19 days at an average of 60º F) and cooler water lengthens incubation time (80 days at an average of 40º F) (Shapovalov and Taft, 1954). Shapovalov and Taft (1954) found that the average incubation time for steelhead eggs in Waddell Creek was 25 to 35 days.

The eggs hatch into a larval form called *alevins* or sac fry. Alevin appear like a small larval fish with a yolk sac distending from the belly. The alevins remain within the interspaces of the gravel until the yolk sac is completely absorbed into the belly. The gravels create a refuge with clear water flowing through, providing oxygenated water and removing metabolic wastes.

Juvenile steelhead fry were found to emerge from the gravels 2-3 weeks after hatching and required another 2-3 weeks to complete emergence (Shapovalov, 1937). Thus, fry may emerge from the gravel between 5 ½ and 11 weeks after spawning in Waddell Creek. Shapovalov and Taft (1954) determined that success of emergence was negatively affected by the amount of fine sediment mixed in with the gravels during emergence. Habitat quality and predation determine survival in the stream after emergence.

Loose gravel, absence of silt, shallow burial and warmer temperatures may quicken emergence, while opposite conditions may lengthen emergence time (Benkman, 1976). A quicker emergence time reduces the chance of the entire progeny being lost after disturbance of the redd.

A.1.4.d Juveniles

Once they emerge from the gravels, juvenile steelhead are very active. They spend most of their time swimming to keep from being swept away, to dart after food, and to find cover. Figure A.14 shows juvenile steelhead and coho from Bean Creek.

Warmer water temperature increases productivity (food supply) and digestive rate, but it also increases the metabolism and food requirements of juvenile fish. Thus, fish may grow more rapidly in warmer water where streamflow and food supply are higher; but they also need more food. They require fast moving water to deliver drifting insects to them for food. Juveniles maintain feeding positions in the stream, catching food as it drifts by.

With reduced summer streamflow, less food is carried to the fish. At the same time, rising water temperature increases the metabolic rate of the fish. If not enough food is supplied to balance the metabolic costs, juvenile salmonids may starve. Juveniles must reach a minimal size before they will migrate to the ocean (called smolting), and the larger they are when they smolt, the greater their survival rate to adulthood in the ocean.

Figure A.14. Small young-of-the-year coho salmon and steelhead captured in Bean Creek

Alley 2005

A young-of-the-year (YOY) coho is pictured on the left, and a steelhead is pictured on the right.

A.1.4.e Importance of juvenile size classes

The length of time that juvenile steelhead spend in freshwater depends on how fast they can grow to smolt size. This depends upon food availability and their metabolic demands. There are two different size classes designated for juvenile steelhead, independent of their age. Measured in the fall, those that are less than 75 mm in standard length (SL) are designated as Size Class 1; those that are equal to or greater than 75 mm SL are designated as Size Class 2. This distinction between size classes is made because size will likely determine different behavior patterns for the next year-and-a-half.

Juveniles in Size Class 1 will likely spend another growing season in the stream before entering the ocean (called smolting), while juveniles of Size Class 2 will likely smolt within the next few months of winter and spring. These smolt-sized juveniles have a much higher survival rate than the smaller fish. Dr. Jerry Smith found that most smolts that had grown to Size Class II by the end of their first growing season (fall) smolted as yearlings in the spring. But most juveniles of the smaller size class remained in the stream an additional year.

Locations of high-density populations of small (Size Class I) YOY fish indicate where much of the spawning has occurred. However, it is much more important to know the locations of high-density populations of smolt-sized juveniles (Size Class II) fish, in order to estimate the number of expected adult returns. This is because Size Class II fish have the highest probability of returning as adults.

A.1.4.f Juvenile habitat requirements

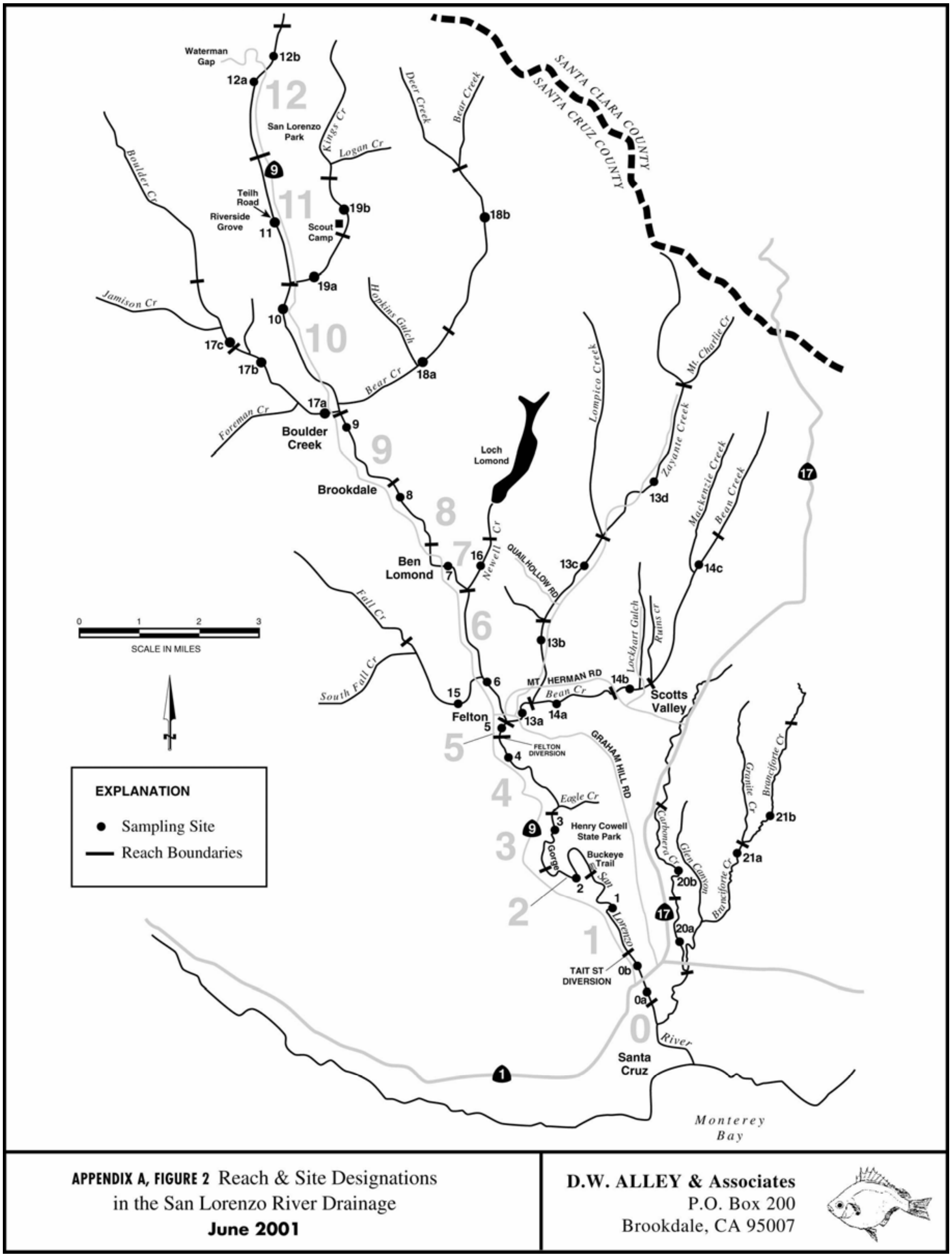
Locations of high-density populations of Size Class II fish are useful indicators of habitat quality. The mainstem of the San Lorenzo River is extremely valuable for its production of smolt-sized juveniles, most of which are fast growing YOY fish.

Every year, many steelhead reach smolt size in just one year in the lower mainstem, downstream of the Zayante Creek confluence, shown on the map as Reaches 0a through 5 in Figure A.15. In these reaches, streamflow, water temperature and food availability are all relatively high. Many juveniles also reach smolt size in one year within the middle mainstem, between the Zayante and Boulder Creek confluences, if conditions are right. Such conditions likely occur in wet years with higher streamflow, shown as Reaches 6 through 9 in Figure A.15.

In most areas of the watershed, young fish require two years of growth to reach smolt size. These areas include the tributaries, the middle mainstem in drier years (because of reduced streamflow) and the upper mainstem in most years upstream of the Boulder Creek confluence in Reaches 10 through 12 in Figure A.15. In these reaches, streamflow and food availability are more limiting to rate of growth. The cooler water temperatures of the shaded areas in the upper mainstem and tributaries contribute to slower growth. Without the streamside trees, however, water temperatures could become too warm for steelhead, recruitment of instream wood would decline and streambank erosion and streambed sedimentation would increase.

The tributaries of the San Lorenzo River provide valuable spawning habitat where most of the YOY steelhead originate. Many of these YOY will then move from tributary spawning areas to the lower and middle mainstem, where they can grow more rapidly. Each year, the tributaries also contribute at least half the smolt sized fish as yearlings and older, slower growing juveniles.

Figure A.15. Reach* and site designations in the San Lorenzo River drainage



*The mainstem river was divided into 3 segments: 1) lower mainstem (Reaches 0-5) from Water St. Bridge to Zayante Cr. confluence, 2) middle mainstem (Reaches 6-9) up to Boulder Creek confluence and 3) upper mainstem (Reaches 10-12) through Waterman Gap.
Source: Alley, 2002.

In the lower and middle mainstem of the San Lorenzo, where summer water temperature is relatively high, juvenile steelhead must use fast-water habitat, such as riffles, runs and the heads of pools, which supply abundant food. In tributaries and upper watershed areas, with limited streamflow and cooler water, juveniles primarily use pools where they feed their heads as fastwater empties into them. They may also use deeper, fastwater habitat called *step-runs*. Most runs and riffles are too shallow for smolt-sized juveniles, but are used by small YOY fish.

Juveniles require escape cover from predators during the spring-summer-fall feeding period and over-wintering shelter from high winter stormflows. During intense stormflows, many juveniles may be flushed out of the system, and spawning redds may be destroyed. Juveniles find escape cover in deep pools, bubble curtains created by water turbulence, cracks and crevices under boulders, undercut banks, bedrock ledges, large instream wood, emergent aquatic vegetation, and overhanging terrestrial vegetation, such as willows. Without sufficient escape cover, juvenile numbers will decline from predation, regardless of food availability or water quality. The larger Size Class 2 fish are more dependent on escape cover and deep water than smaller juveniles. Excessive fine sediment--entering the stream channel from eroding areas—makes pools shallow, and embeds or buries boulders, eliminating escape cover.

The middle mainstem has been substantially impacted by sedimentation and fluctuations in summer baseflow. Correlation analysis showed some habitat partitioning between size classes where larger Size Class 2 fish dominated deeper pools, and smaller Size Class 1 fish (all of them YOY fish) were found more in riffles and runs (Alley et al., 2004a). Alley et al. (2004) found all size classes to be negatively correlated to riffle embeddedness, suggesting that this parameter is important to monitor and improve to recover population numbers. Smith (1982) developed an empirical model that predicted the density of smolt-sized juvenile steelhead at sites in small Santa Cruz County streams (including tributaries of the San Lorenzo) based on the positive correlation between smolt size juvenile densities and water depth and amount of escape cover in aquatic habitat.

A.1.4.g Smolts

When juvenile steelhead reach smolt size in the San Lorenzo drainage, they migrate to the Monterey Bay primarily between March and May (Smith and Alley, unpublished data from 1987-88). Salmonid survival to adulthood in the ocean increases with smolt size (Shapovalov and Taft 1954).

Before migrating to the sea, juveniles change in shape, weight, color and physiology during a process called *smoltification*. They change color, becoming silver with black-tipped fins. They may spend some time in the estuary, feeding, adapting to the salinity changes, and growing. In saltwater, they must drink water and have their gills and kidneys excrete the excess salts afterwards. In freshwater the fish must not absorb water, but must retain salts.
While some steelhead never leave freshwater (e.g., those that remain as resident rainbow trout often in inaccessible headwaters areas), most steelhead in the San Lorenzo River watershed migrate a relatively short distance to the sea.

Little is known about the ocean phase of steelhead. While at sea, steelhead feed upon krill, planktonic organisms, squid and other fish (Love, 1996). Steelhead, like other salmonids, school in large aggregations at sea and are highly migratory. A steelhead tagged in Washington was caught at the tip of the Aleutian Islands, Alaska, a distance of 2,275 miles (Love, 1996). The National Marine Fisheries Service (NMFS) and coastal universities are conducting research to learn more about the behavior and growth rates of steelhead and other salmon at sea. Scientists use tags, radio tracking and ear-bone (otolith) microchemistry in this research.

During their ocean phase, steelhead range further south than other salmonids. Unlike coho and other salmon species, steelhead are not fished commercially. NOAA fisheries research has demonstrated that different species compete for the same food source in the ocean. Steelhead and Chinook salmon sometimes feed on the same species of invertebrates. According to the local Big Creek Hatchery manager, approximately 240,000 juvenile Chinook salmon are brought from San Joaquin River hatcheries to pens in Santa Cruz for imprinting prior to annual release into the Monterey Bay (Strieg, 2006). These planted Chinooks, along with native Chinooks, compete with native steelhead and coho salmon in the bay.

A.1.5 Natural history of coho salmon

Coho salmon, also called silver salmon, range from Asia, across the Bering Strait to Alaska, and south along the Pacific coast of North America. Historically, the southern end the range of coho salmon was streams that flow out to the Monterey Bay, including the San Lorenzo River. Juvenile coho had not been documented during fall sampling of the San Lorenzo drainage since 1981, when several were caught and released in 2005 in Bean Creek, a tributary of the San Lorenzo River (Alley, 2006). These fish were members of the strongest year class (Year 3) of coho for the local area. There are viable populations of coho salmon in Scott and Waddell creeks.

Within the San Lorenzo River watershed, anecdotal evidence indicates that a small coho population once inhabited the middle mainstem and cooler reaches of lower gradient tributaries, such as Zayante, Bean and Kings creeks.

Coho salmon reach 38.5 inches in length, can weigh up to 31 pounds, and may live as long as five years (Love, 1996). Usually, they live three years in streams south of San Francisco Bay. Coho have a much more rigid life cycle than steelhead. They spend only one year in freshwater and two at sea, which creates distinct year classes. At any given time, there are essentially three different cohorts, or year classes of coho in a population specific to a given stream drainage. The size of the returning adult numbers is dependent upon the size and success of the juvenile population three years before. If migration is difficult, spawning is largely unsuccessful or rearing habitat conditions are poor, then an entire year class is affected and becomes weak. This year class remains weak at three-year intervals. If conditions are bad on a three-year interval, the entire year class may be eliminated. The three separate year classes of coho create distinct generations within every local population. If one of these generations is unable to reproduce, that year class can be lost forever unless it is recreated from hatchery plantings. This situation makes coho very susceptible to natural or anthropogenic changes in environmental conditions, and less adaptable than steelhead.

A.1.5.a Spawning

Coho migrate upstream and spawn earlier than steelhead. Most adults migrate upstream between November and February, but some spawn as late as March. Their ability to access spawning grounds depends on streamflow and storm patterns over the winter. As with steelhead, coho await the opening of sandbars at river mouths by winter runoff. At low streamflows, impediments are more likely to delay upstream migration, and adults may wait, just below the temporary barrier, for streamflow to increase. Because coho spawn earlier than steelhead, their redds are more vulnerable to destruction or suffocation from sedimentation resulting from later winter stormflows.

Upon entering fresh water streams, adult coho salmon undergo distinct biochemical and hormonal changes in response to the change in salinity and their intestinal tracts atrophy. Males undergo more extreme morphological changes than females by developing hooked jaws, as shown in Figure A.16. Once migration is initiated, adults stop feeding and begin to deteriorate with and death after spawning inevitable.

Figure A.16. Morphological changes in ocean and freshwater life stages of coho salmon.

Males generally migrate upstream first, wait for females, and establish a hierarchical ranking. Females select spawning sites with high water flow through gravel, which provides sufficient oxygen for the eggs. Redds are constructed by the female at the tail of a pool or glide that is followed by a steep riffle. She spawns in the deepest part of the stream cross-section, to avoid dewatering of the nest. This placement provides a relatively shallow section, with an even bottom of gravel and enough streamflow to nurture the eggs and larvae. Coho require spawning beds of deep, loosely aggregated gravels with a minimum of fine sediments. Gravels in the range of 5 to 90 mm are optimal for salmonid spawning beds (Alley et al., 2004a; Alley, 2002). Once she selects a spawning site, the female lies on her side and flaps her tail to excavate a pit in the streambed. After the eggs are laid and fertilized, the female uses the same tail movements upstream of the pit to cover the eggs with gravel. Over several days, she may lay several more pockets of eggs, like this, in a line upstream (US Fish and Wildlife, 2006). The later spawning steelhead may spawn in the same vicinity to either scour out the coho redds or bury them.

Spawning success for steelhead populations is dependent upon the size of the run, extent of streams accessible, and spawning gravel conditions. Smith (1982) reported that although good spawning substrate is sparse throughout the San Lorenzo watershed, it rarely restricts steelhead smolt production. The San Lorenzo River Salmonid Enhancement Plan (Alley et al., 2004a) reported that spawning habitat was abundant enough, and steelhead fecund enough to produce enough juveniles to saturate the limited juvenile habitat in most years; but that spawning conditions were sub-optimal, and limited.

A.1.5.b Incubation and emergence

Incubation time varies inversely with water temperature; cooler waters lengthen incubation time. Shapovalov and Taft (1954) found that the average incubation time for coho salmon eggs in Waddell Creek was 35 to 50 days. Like steelhead eggs, coho eggs hatch into a larval form called *alevins* or sac fry. Emergence of juvenile coho salmon from the gravels begins two to three weeks after hatching, and is completed within two to seven weeks of hatching. Peak emergence occurs at approximately three weeks (Shapovalov and Berrian, 1940).

Emergence of fry may occur 7 to14 weeks after spawning in Waddell Creek, depending on water temperature. Loose gravel, absence of silt, shallow burial, and warmer temperatures hasten coho emergence, as with steelhead. Spawning areas in the lower and middle mainstem are likely warmer than Waddell Creek, leading to faster egg development and fry emergence, particularly in late spring. As with steelhead, survival rates of coho eggs and fry as they emerge from the gravel are reduced as the percent of fine sediment in the gravels increases.

A.1.6 Juvenile coho

While many of the habitat requirements for juvenile coho are similar to those of steelhead, coho prefer lower gradient reaches, cooler water temperatures, deeper pools and more escape cover, such as submerged rootwads, large logs, and unembedded boulders. These habitat characteristics are abundant in old growth forests. The decline in coho populations has been attributed to the widespread cutting of old growth forests (Brown et al., 1994). Juvenile coho primarily inhabit pools; they are unable to swim as well as steelhead in faster moving water. Coho habitat is negatively affected by sedimentation and water diversion. Few areas remaining in the San Lorenzo River watershed provide good quality coho salmon habitat because they require cool, low-gradient (flat) stream reaches. Most flat reaches in the watershed are too warm. Much of the cool, flat habitat has very low summer baseflow, and some is extremely vulnerable to dewatering by well pumping (Alley, personal observation, 2005).

A.1.7 Coho smolts

Juvenile coho smolt primarily from March through early June, approximately one year after they emerge from the gravel. During smoltification, juveniles change in shape, weight, color and physiology, and they increase their ability to excrete salts to prepare for living in saltwater. They may spend time in the lagoon adapting to the salinity changes, feeding, and growing. Smolts become silver in color.

Coho salmon spend 1-2 years at sea before returning to streams to spawn. All female coho spend two years at sea, while many males may return to their natal stream after only one year at sea. In the ocean, the small coho salmon feed primarily on small invertebrates such as krill. As they become larger, they feed on squid and small fish such as herrings, anchovies, rockfish and sand lances (Love, 1996).

The range of coho salmon while at sea is not well documented. During their first year at sea, coho salmon stay near their natal streams; later they may range far to the north, over the continental shelf (Brown et al., 1994; Love, 1996). They can migrate up to 1,000 miles from their natal streams (Love, 1996).

A.2 Ecological role of salmonids

As key predators, juvenile salmonids help keep fresh water aquatic ecology in balance. When they return from the ocean to their natal streams, anadromous salmonids bring nutrients into freshwater ecosystems. Carcasses of anadromous fish are an integral part of nutrient cycling for both aquatic and riparian systems; declines in anadromous species may cause fundamental changes in ecosystems and the loss of species (Spence et al., 1996). Salmonid carcasses, when numerous, contribute significant amounts of nitrogen and phosphorous compounds, the nutrients most often limiting production in headwater streams (Spence et al., 1996). Bilby et al. (1996) showed that 18% of the nitrogen in the foliage of Western hemlock, devil’s club and salmonberry, growing within 5 m of a small stream in western Washington is derived from spawning coho salmon.

If there were still 25,000 adult steelhead and 5,000 adult coho returning to the San Lorenzo River watershed, then their contribution of nitrogen and phosphorous might be significant. Under current conditions, adult steelhead carcasses are seldom seen and coho have been functionally eliminated from the system.

Aquatic and terrestrial predators, as well as scavengers, throughout the salmonid range depend on them for food. Birds and other terrestrial organisms cycle salmonid biomass and nutrients through the terrestrial ecosystem. Bacteria and other decomposers break down salmonid carcasses to recycle nutrients that support the productivity of the aquatic ecosystem.

A.3 Decline of salmonids throughout their range

Both coho salmon and steelhead were once common and widespread throughout the coastal streams of the Pacific coast. Coho salmon historically occurred in as many as 582 California streams, from the Oregon boarder to their southern limit around the Monterey Bay (Brown et al., 1994). Salmon have disappeared from nearly half of their historical spawning streams in the Pacific Coastal states (Pacific Coastal Salmonid Conservation and Recovery Initiative, 2000). Brown et al. (1994) reported that coho populations today are probably less than six percent of what they were in the 1940s. Furthermore, there has been at least a 70 percent decline since the 1960s.

A.3.1 Decline of coho

The Central California Coast coho salmon forms a separate evolutionarily significant unit (ESU) of the species, extending from Punta Gorda in Northern California to the San Lorenzo River.

This means that the San Lorenzo River marks the southern end of the ESU range. As a result, the challenges this salmon faces are more extreme than those faced by their northern relatives, in terms of elevated stream temperatures and reduced streamflows (NMFS, 2005).

The Central California Coast Coho Salmon ESU was listed under the federal Endangered Species Act as a threatened species in 1996. Accessible reaches of the San Lorenzo River (excluding stream reaches above Newell Creek Dam) were included within the critical habitat designation for the ESU. In response to a petition filed by the timber industry to de-list coho, NMFS undertook a status review to update information about the species. The petition claimed that coho did not exist historically in central California. NMFS rejected the petition to de-list. Furthermore, the agency determined that the species should be listed as endangered rather than threatened. In 2005, coho were listed as endangered under the federal Endangered Species Act (ESA). Coho salmon south of San Francisco Bay were previously listed as an endangered species by the state of California.

NMFS began the recovery plan for the Central California Coast Coho Salmon ESU in 2005, as required by the federal ESA. Recovery is the process in which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the federal ESA are no longer needed. A variety of actions may be necessary to achieve the goal of recovery, such as the ecological restoration of habitat or implementation of conservation measures with stakeholders (NMFS, 2004). Section A.8, Salmonid Recovery discusses this topic in more detail.

In their report on the status and decline of coho salmon in California, Brown et al. (1994), identified four broadly defined threats that have negatively impacted salmonids:

1. Loss of stream habitat
2. Interactions with hatchery fish, which can produce a loss of genetic integrity, and an increase in competition and disease
3. Overexploitation
4. Climatic factors, such as oceanic conditions and precipitation.

Loss of stream habitat is widely acknowledged as the single most significant factor contributing to the decline of coho throughout California (Brown et al., 1994; Pacific Coast Salmonid Conservation and Recovery Initiative, 2000).

Over at least the past 60 years, the loss of coho salmon habitat has been cumulative (Brown, et al., 1994). Logging, with unpaved roads and skid trails, causes severe habitat degradation for coho salmon (Brown et al., 1994). Habitat loss is extensive in watersheds impacted by early logging with continued sedimentation (Brown et al., 1994). Coho salmon habitat loss from current logging practices still occurs due to accelerated sedimentation (Brown et al., 1994). Burns (1972) indicated that logging severely reduced the number of coho salmon smolts emigrating out of watersheds in California waterways (as cited in Brown, et al., 1994). Graves and Burns (1970) found that smolts emigrated at much smaller sizes from logged watersheds than from untouched watersheds, due to stress from habitat degradation in the logged watersheds (as cited in Brown et al., 1994). Survival rate of smolts to the returning adult stage is positively correlated with larger size at smolting, as stated earlier.

Researchers believe that most natural production of coho salmon in the smaller streams south of San Francisco were lost due to the 1976-1977 drought. The drought exacerbated the cumulative watershed conditions already impacting the species in this area (Brown et al., 1994). The El Niño winters of 1992 and 1983 further diminished local coho populations, due to high rainfall and winter runoff, associated ocean warming and food scarcity in the ESU range, and major damage to streambeds from severe landsliding and sedimentation. These factors severely reduced the survival rate of salmonid juveniles to adulthood. The drought years of 1987-1992 undoubtedly added catastrophic impacts to coho spawning success and juvenile survival.

A.3.2 Decline of steelhead

The US Fish and Wildlife Service adopted a final rule, designating steelhead in the Central California Coast ESU as a federally threatened species, effective October 17, 1997 (US Fish and Wildlife Service, 1998).

At this time, the designation applies only to naturally spawned populations of anadromous forms of *O. mykiss,* residing below long-term naturally occurring or man-made impassable barriers. The San Lorenzo River is included in critical habitat designated for all accessible reaches, except for stream reaches above Newell Creek Dam. Steelhead south of San Francisco Bay are considered a sensitive species by the state of California.

Loss of steelhead and coho habitat has resulted from dams, water diversions, increased stream water temperatures, stream alterations, sedimentation, excessive scour and other impacts associated with agriculture, logging, mining, urbanization, roads and development. These activities are associated with a dramatic reduction in habitat complexity, including the reduction in large instream wood and an increase in sedimentation (Sanderlock, 1991 as cited in Brown et al., 1994). Napolitano (1998) reports high quality fish habitat results from complexity and stable conditions.

Impacts from specific forest practices on salmonid growth and survival and on aquatic habitat are shown in Tables A.1 and A.2. Table A.1 best describes impacts outside the fog belt and Table A.2 describes impacts within the coastal zone, which receives most of the benefits of fog drip.

Table A.1. Forest practices outside the fog belt and their potential impacts to stream environments, habitat quality, and salmonid growth and survival

Forest practice	Potential impact to physical stream environment	Potential impact to quality of salmonid habitat	Potential consequences for salmonid growth and survival
Timber harvest in riparian areas	Increased incident solar radiation	Increased stream temperature; higher light levels; increased autotrophic production	Reduced growth efficiency; increased susceptibility to disease; increased food production; changes in growth rate and age at smolting
	Decreased supply of large woody debris	Reduced cover; loss of pool habitat; reduced protection from peak flows; reduced storage of gravel and organic matter; loss of hydraulic complexity	Increased vulnerability to predation; lower winter survival; reduced carrying capacity; less spawning gravel; reduced food production; loss of species diversity
	Addition of logging slash (needles, bark, branches)	Short-term increase in dissolved oxygen demand; increased amount of fine particulate organic matter; increased cover	Reduced spawning success; short-term increase in food production; increased survival of juveniles
	Erosion of streambanks	Loss of cover along edge of channel; increased stream width; reduced depth	Increased vulnerability to predation; increased carrying capacity for age-0 fish, but reduced carrying capacity for age-1 and older fish
		Increased fine sediment in spawning gravels and food production areas	Reduced spawning success; reduced food supply
Timber harvest on hill slopes; forest roads	Altered streamflow regime	Short-term increase in streamflows during summer until secondary forest growth develops	Short-term increase in juvenile survival
		Increased severity of some peak flow events	Embryo mortality caused by bed-load movement
	Accelerated surface erosion and mass wasting	Increased fine sediment in stream gravels	Reduced spawning success; reduced food abundance; loss of winter hiding space
		Increased supply of coarse sediment	Increased or decreased rearing capacity
		Increased frequency of debris torrents; loss of instream cover in the torrent track; improved cover in some debris jams	Blockage to migrations; reduced survival in the torrent track; improved winter habitat in some torrent deposits
	Increased nutrient runoff	Elevated nutrient levels in streams	Increased food production
	Increased number of road crossings	Physical obstructions in stream channel; input of fine sediment from road surfaces	Restriction of upstream movement; reduced feeding efficiency
Scarification and slash burning (preparation of soil for reforestation)	Increased nutrient runoff; Inputs of fine inorganic and organic matter	Short-term elevation of nutrient levels in streams; increased fine sediment in spawning gravels and food production areas; short-term increase in biological oxygen demand (BOD).	Temporary increase in food production; Reduced spawning success

Source: Spence et al., 1996.

A.4 Decline of salmonids within the San Lorenzo River watershed

The San Lorenzo River watershed provides over 80 miles of stream habitat for anadromous salmonids (Ricker and Butler, 1979). The San Lorenzo River fishery once added significant value both to the county's economy and to the experience of individual anglers.

A.4.1 Decline of steelhead in the watershed

According to the CCRWQCB (2002), "The San Lorenzo River once held the distinction of having the largest steelhead fishery south of San Francisco." The California Department of Fish and Game (CDFG) estimated that 20,000 adult steelhead were present in the San Lorenzo River prior to 1965 (Johansen, 1975). This estimate included any rainbow trout/steelhead larger than 14 inches in length (Strieg, 2005). In the mid-1960's, CDFG estimated that 19,000 adult steelhead inhabited the watershed. NOAA Fisheries estimated the number of adult steelhead in the watershed in 1966 at 500. However, these estimates of historic adult steelhead numbers were anecdotal and lacked supportable scientific evidence. Most estimates were based on creel census data, which reflect the extensive planting program rather than natural production. However, it may be assumed that the steelhead population was greatly reduced from the habitat degradation documented in the 1960's and 1970's, following extensive clear-cut logging and fast-paced suburban development.

Scientifically supportable estimates of juvenile steelhead density first occurred in 1981, when Smith and Alley conducted habitat surveys and sampled juvenile steelhead densities by electrofishing throughout Santa Cruz County (Smith, 1982). Comprehensive estimates of habitat conditions and juvenile population estimates in the San Lorenzo watershed were resumed in 1994 by D.W. Alley & Associates, and have continued through 2005. Although there were likely much larger juvenile populations prior to clear-cut logging and housing development in the 1960s and 1970s, these data suggest a fairly stable juvenile steelhead population from 1981 to 2005, with year-to-year fluctuations. Juvenile numbers have been negatively affected by El Niño events. Poor adult returns resulted from oceanic food shortages, juveniles being flushed out to sea during high stormflows, increased erosion and stream sedimentation from heavy stormflows.

Drier years with reduced streamflow also resulted in smaller juvenile numbers, because of reduced habitat and slower juvenile growth rates. Juvenile numbers have increased in years, such as 2002, when the heaviest stormflows came early in the winter with milder storms. This resulted in less sediment movement and better water clarity after storms. Indices of adult population size for the San Lorenzo River watershed ranged between 1,600 and 2,650 during the period 1998-2001, with juvenile populations ranging between 103,000 and 171,000 (Alley, 2002). These are the best estimates to date from systematically collected data. Adult indices are probably conservatively low, based on the underlying assumptions of the Kelley et al. (1987) model and a 50% reduction factor applied to the number of adults generated by the model from juvenile numbers (Alley, 2002).

The steelhead population has not recovered. NMFS listed steelhead as a threatened species in the Central California Coast Evolutionary Significant Unit (ESU), which includes the San Lorenzo River. The San Lorenzo River watershed has suffered major spawning and rearing habitat degradation. Human-induced habitat loss and degradation resulted from 1) early clear-cut logging that increased erosion, reduced stream shading and diminished summer streamflow with loss of fog drip, 2) contemporary logging since 1960 (clear-cut and later selection cut) that inadequately buffered the riparian corridor from timber harvest and has accelerated erosion from road and skid-trail construction, increased winter storm runoff, reduced summer baseflow with loss of fog drip and reduced large instream wood recruitment, 3) quarrying of sand and gravel that cleared vegetation and increased erosion, and 4) increased human development that brought more vegetation clearing, impermeable surfaces and altered drainage patterns. These land-use patterns increased stormflow peaks, erosion and water demand, resulting in increased surface water diversion and well pumping.

A.4.2 Decline of coho in the watershed

Historic and recent population estimates suggest a worse decline for coho salmon than for steelhead in the San Lorenzo River watershed. The coho salmon population in the early 1950's, prior to hatchery plantings, was described as "small" by Willis Evans, retired CDFG fishery biologist and the last Brookdale Hatchery Manager (Alley and Evans, personal communication 2001). Evans said spawning occurred in the middle mainstem (Reaches 6-9) and eastern tributaries, such as Zayante and Bean creeks, shown in Figure A.15. The coho population was estimated as high as 2,500-10,000 in 1964 (Johnson, 1964), and as low as 750 in 1980 by CDFG staff (CCRWQCB staff report for TMDL, 2001). However, there was no scientific evidence on which to base these estimates. Since systematic juvenile sampling began in 1981, coho juveniles have been detected only in 1981 (Bean and Fall creeks) and in 2005 (Bean Creek). According to NOAA Fisheries, coho salmon were extirpated from the watershed through a combination of habitat loss and five consecutive years of drought conditions, 1987-92 (J. Ambrose, NOAA Fisheries, personal comm.). The severe droughts of 1976-77 undoubtedly made adult fish passage through the San Lorenzo River gorge difficult for coho salmon.

Although coho salmon historically inhabited many coastal streams in San Mateo and Santa Cruz counties, presently they are known to occur south of San Francisco Bay in only San Gregorio, Pescadero, Gazos, Waddell, Scott Creek and San Vicente creeks. Of these creeks, only Scott Creek has three intact year classes. Waddell has two mediocre year classes (Jerry Smith, personal communication). San Vicente Creek probably has two year classes present. San Gregorio, Pescadero and Gazos creeks have only one year class present.

A.4.3 Habitat conditions 1950-1975

Habitat conditions in the watershed were good in the 1950s and then substantially worsened in the 1960s and 1970s, due to clear-cut logging and increased human development. A CDFG survey of Bear Creek in 1956 and of Zayante Creek in 1959 found that habitat conditions were good, but expected to soon worsen following the clear-cut logging that was scheduled to occur in 1960. As expected, a CDFG survey of Zayante Creek in 1966 and 1974 found that extensive habitat damage had resulted from the logging that occurred without riparian protection. Boulder Creek had poor substrate conditions by 1960 and again in 1966, according to CDFG surveys. Kings Creek also had poor conditions by 1966. CDFG stream survey reports for Bear Creek showed poor conditions in 1974.

Other CDFG surveys indicated that substrate conditions in the mainstem San Lorenzo had badly deteriorated to very sandy conditions by 1972. A 1966 CDFG survey estimated the streambed to

be 35% cobble, 20% gravel and 25% sand and silt. The 1972 CDFG survey estimated the streambed to be 3% cobble, 2% gravel and 76% sand and silt.
Suburban residential development increased during this same period, as summer homes were converted to year-round dwellings. Between 1970 and 1976, 280 new homes were built each year. From 1960 to 1976, the watershed population nearly tripled (Ricker and Butler 1979). This increased housing development was accompanied by inadequately constructed or poorly maintained roads (Ricker and Butler 1979).

A.4.5 Recent habitat conditions

Natural processes create aquatic habitats that are critical to salmonids (Spence et al., 1996). Different aquatic habitats are required for different salmonid life stages. For example, graveled-glides are used for adult spawning, fast water habitat is used for juvenile feeding, and pools provide juvenile cover and feeding areas. Large objects in the channel provide slackwater resting sites for overwintering juveniles and migrating adults.

The most common aquatic habitat types within the San Lorenzo River watershed are pools, riffles, runs and step-runs. Lateral scour pools are the most common pool types.

Measurable physical characteristics of aquatic habitats include stream width, streamflow, water depth, escape cover (amount and source of cover), percent embeddedness of larger cobbles and boulders (portion of rocks buried in finer material), streambed composition (percent fine sediment (mostly sand) versus gravel or larger rocks), stream shading (percent canopy closure) and percent of the riparian canopy that is deciduous versus evergreen. Table A.3 lists the percentage of riparian canopy closure by reach within the San Lorenzo River watershed.

Table A.3 Baseline riparian tree canopy closure in the San Lorenzo River watershed. (Refer to map in Figure 4-6)

Reach Designation	Reach Location	Average % Tree Canopy Closure by Reach	Year of Measurement
1	Lower Mainstem- Paradise Park	44	2006
4	Lower Mainstem- Upper Henry Cowell Park	32	2006
6	Middle Mainstem- Above and below Fall Creek Confluence	62	2006
7	Middle Mainstem- Downstream of Ben Lomond Summer Dam	50	2005
8	Middle Mainstem- Downstream of Clear Creek Confluence	51	2006
9	Middle Mainstem- Downstream of Boulder Creek Confluence	57	2005

10	Upper Mainstem- Downstream of Kings Creek Confluence	80	2005
11	Upper Mainstem- Up and Downstream of Teilh Road Bridge	79	2006
12b	Upper Mainstem- Waterman Gap Upstream of Highway 9 Bridge	86	2005
13a	Zayante Downstream of Bean Creek Confluence	84	2006
13b	Zayante Upstream of Lowermost East/ West Zayante Road Bridge	70	2005
13c	Zayante Upstream of Quail Hollow Road Bridge	71	2005
13d	Zayante Mostly Upstream of East Zayante Road Bridge	83	2006
13e	Lower Lompico Creek, Upstream of Bridge Crossing Above Fish Ladder	81	2006
14a	Lower Bean Above Zayante Confluence	84	2005
14b	Middle Bean Downstream of Lockhart Gulch Confluence	72	2005
14c	Bean Above Mackenzie Confluence	79	2006
16	Newell Between Glen Arbor Bridge and the Next One Upstream	75	2006
17a	Lower Boulder Above Highway 9 Bridge	81	2006
17b	Middle Boulder Mostly Above Big Basin Way Bridge Into Bracken Brae	84	2005
17c	Upper Boulder Above Bracken Brae	82	2005
18a	Bear Upstream from Pool Under Oso Viejo Road Bridge to Bear Creek Country Club	78	2006
21b	Branciforte Upstream from Happy Valley School	75	2005

Source: Alley 2007.

Table A.4 quantifies some of the steelhead habitat characteristics within the San Lorenzo River watershed.

Table A.4. Habitat proportions and percent contribution of juvenile production to adult steelhead index of mainstem segments and major tributaries of the San Lorenzo River watershed*

Mainstem segment or tributary	Average % pool**	Average % fastwater habitat**	% of watershed's steelhead habitat length in dry years (miles of habitat***)	% juvenile contribution to adult index
Lower mainstem (above Tait Street)	44	56	13 (7.6 miles)	19
Middle mainstem	70	30	15 (8.9 miles)	6.1
Upper mainstem	62	38	14 (8.4 miles)	13.2
Branciforte	71	29	7.7 (4.6 miles)	8.2
Carbonera	56	44	5.7 (3.4 miles)	4.3
Fall	25	75	2.7 (1.6 miles)	3.3
Zayante (to Mt. Charlie Gulch)	64	46	9.6 (5.7 miles)	13.5
Bean	49	51	9.1 (5.5 miles)	10.0
Newell	63	37	1.8 (1 mile)	1.3
Boulder	57	43	6.1 (3.5 miles)	7.3
Bear	67	33	8.1 (4.7 miles)	10.0
Kings	66	34	6.5 (3.7 miles)	3.8

* Source: Alley 2002.
** Averages of percent habitat proportions for habitat typed reaches in each mainstem segment or tributary.
***Habitat mileage is a conservative estimate, typical of an especially dry year like fall 1981.
Refer to our county-wide Steelhead and Coho Salmon Distribution Map (2004) for best estimates of typical steelhead distribution in tributaries of the San Lorenzo River watershed.

A.5 Aquatic habitat typing

Terms used to identify aquatic habitat types are defined in Table A.5.

Table A.5. Terms used in aquatic habitat typing.

Term	Habitat description
Riffle	Shallow swiftly flowing, turbulent water with some partially exposed substrate, usually cobble dominated. "Low gradient" riffles = channel gradient of <4%. "High gradient" riffles = channel gradient of >4%.
Cascade	Steepest riffle habitat, with alternating small waterfalls and shallow pools. Substrate usually bedrock and boulders.
Bedrock sheet	Thin sheet of water flowing over a smooth bedrock surface. Gradients highly variable. Fairly common in headwater situations, especially north of Zayante Fault, and at geological interfaces within San Lorenzo River watershed.
Pocket water	Section of swift flowing stream containing numerous boulders or other large obstructions, with eddies or scour holes behind obstructions. Generally found in larger mainstems.
Glide	Wide uniform channel bottom. Low to moderate flow velocities, lacking pronounced turbulence. Substrate usually consists of cobble, gravel, and sand. Generally, wide and relatively shallow, with smooth bottom. Generally located at tails of pools in San Lorenzo River watershed.
Run	Swiftly flowing with little surface disturbance, and no major flow obstructions. Often appear as flooded riffles. Typical substrate consists of gravel, cobble, and boulders; bottom may be uneven and rough.
Step-run	A sequence of runs separated by short riffle steps. Substrate usually cobble and boulder dominated. Generally found in headwaters or gorges within San Lorenzo River watershed.
Edgewater	Quiet, shallow area found along margins of stream, typically associated with riffles. Water velocity low or lacking. Substrate varies from cobbles to boulders.
Pool	Large, deep-water section of stream. Pools formed by scour, and classified by scour type.
Mid-channel pool	Large pool formed by mid-channel scour. Scour hole encompasses > 60% of wetted channel. Slow water velocity; substrate highly variable.
Channel confluence pool	Large pool generally formed at confluence of two or more channels.
Corner pool	Lateral scour pool formed at bend in channel. Often a bedrock wall or solid channel barrier outside edge, deflecting stream velocity to scour pool.
Lateral scour pool	Formed by flow scouring around partial channel obstruction. Scour generally confined to < 60% of wetted channel. Scour objects may be logs, rootwads, boulders, bedrock or artificial.
Plunge pool	Located where stream passes over channel obstruction, dropping steeply into streambed belo Resulting scoured out depression often large and deep. Substrate size variable. More common in headwaters, and accompanying old-growth instream wood.
Dammed pool	Water impounded from channel blockage, such as large instream wood, rockslides, or artificial barriers. Substrate tends toward smaller gravel and sands.
Step pool	Series of pools separated by short riffles or cascades; generally found in high gradient, confined mountain streams dominated by boulder substrate.
Secondary channel pool	Mainly associated with gravel bars, sand or silt substrate. In summer, pools dry up, become isolated or have little flow.
Backwater pool	Located along channel margins; caused by eddies around obstructions such as boulders, rootwads, or logs; generally shallow; dominated by fine grain substrate. Low current velocities.

Source: Adapted from the original system developed by Bisson, et al. (1981), modified by Decker, Overton (1985), Sullivan (1988), and Snider (1990).

The most common aquatic habitat types within the San Lorenzo River watershed are pools, riffles, runs and step-runs. Lateral scour pools are the most common pool types.

Measurable physical characteristics of aquatic habitats include stream width, streamflow, water depth, escape cover (amount and source of cover), percent embeddedness of larger cobbles and boulders (portion of rocks buried in finer material), streambed composition (percent fine sediment (mostly sand) versus gravel or larger rocks), stream shading (percent canopy closure) and percent of the riparian canopy that is deciduous versus evergreen.

A.5.1 Local stream reaches

Watersheds are divided into stream reaches, based on their habitat characteristics. Within each reach, each habitat characteristic is tallied, and then averaged for each reach. In this way, for example, the average percent canopy closure is calculated for each reach. Within each reach, the percentage of each habitat type is also calculated. In this way, for example, the percent of pool habitat within the stream length is calculated for each reach.

Based on channel morphology and other habitat characteristics, the mainstem San Lorenzo River has been divided into four sections (Alley, 2002):

Upper mainstem– upstream of Boulder Creek confluence into Waterman Gap and headwaters.
Middle mainstem– between the Boulder Creek and Zayante Creek confluences.
Lower mainstem– San Lorenzo gorge and alluvial reaches below Zayante Creek confluence.
Tributaries-form subwatersheds as they flow into the mainstem.

A.5.1.a Upper mainstem

The upper mainstem has relatively low spring and summer baseflow, is well-shaded with cool water. Here, juvenile steelhead require two years to reach smolt size except during the wettest years. Most juveniles reside in pools. The upper mainstem also has relatively high densities of yearlings, which contributed significantly to the adult steelhead index in 2001 (Table A.6). Between the Boulder Creek and Kings Creek confluences, the mainstem is low gradient, has steep canyon walls with tall redwoods, and is dominated by long, sediment-laden pools separated by short, shallow riffles (Table A.6). Large Sacramento suckers are found under banks and large wood in pools of this stretch. Further upstream, as stream gradient increases, the pools become shorter and habitat variety increases. Limiting factors to salmonids in the upper mainstem include low spring and summer streamflow and sedimentation from erosion, as shown in Figure A.17.

Figure A.17. Streambank erosion on the upper San Lorenzo River

Alley 2005

A collapsing streambank is a source of sedimentation of the streambed in the upper San Lorenzo River.

Table A.6 Habitat proportions & percent contribution of juvenile production to adult steelhead index of mainstem segments & major tributaries of the San Lorenzo River watershed*

Mainstem Segment Or Tributary	Avg % Pool**	Avg % Fastwater Habitat**	% of Watershed's Steelhead Habitat Length in Dry Years (miles of habitat***)	% Juvenile Contribution To Adult Index
Lower mainstem (above Tait Street)	44	56	13% (7.6 miles)	19
Middle mainstem	70	30	15% (8.9 miles)	6.1
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Branciforte	71	29	7.7% (4.6 miles)	8.2
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Boulder	57	43	6.1% (3.5 miles)	7.3
Bear	67	33	8.1% (4.7 miles)	10.0
Kings	66	34	6.5% (3.7 miles)	3.8

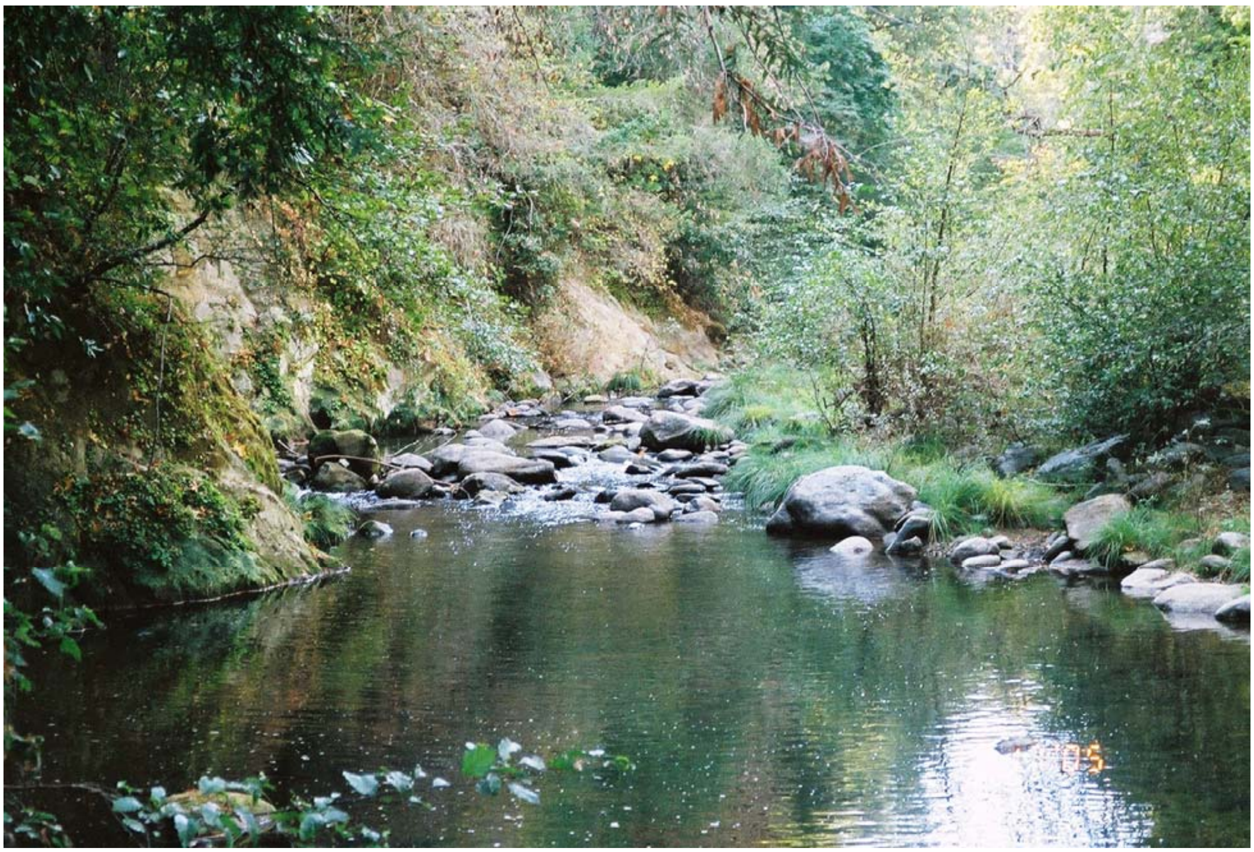
* Source: Alley, 2002.
** Averages of percent habitat proportions for habitat typed reaches in each mainstem segment or tributary.
***Habitat mileage is a conservative estimate, typical of an especially dry year like fall 1981. Refer to county-wide Steelhead and Coho Salmon Distribution Map (2004) for best estimates of typical steelhead distribution in tributaries of the San Lorenzo River watershed.

A.5.1.b The middle mainstem

The middle mainstem begins below Boulder Creek. Bear, Boulder and Clear creeks enter its upper end as tributaries, which contribute large, granitic streambed cobbles and boulders. Tributaries also help to seed the middle mainstem with YOY juvenile steelhead. The middle mainstem has higher streamflow than the upper mainstem and a wider, sunnier canyon. Its increased gradient creates more fastwater feeding habitat (riffles and runs) and better aquatic insect habitat. Riffles, runs and heads of pools are the primary habitats for juveniles. Figure A.18 shows habitat provided by bedrock scoured pools. Water temperatures are warmer, forcing juvenile steelhead to use fastwater habitat to feed. Approximately 70-80% of the length of the middle mainstem is dominated by long, deep pools containing insufficient food for juvenile steelhead, except at the heads of the pools. Spawning habitat is limited. As Table A.6 shows, since 1999, juvenile densities have been low here.

Limiting factors to salmonids in the middle mainstem include periodic onslaughts of sediment from the tributaries (particularly Kings, Bear and Boulder creeks with continued logging and poorly constructed rural roads) and the lack of large instream wood that would counter negative effects of sediment. The other primary limiting factors are low spring and summer streamflows that are worsened by District surface water diversions in the Boulder and Clear Creek sub-watersheds, water storage on Newell Creek (City of Santa Cruz's Loch Lomond) and California-American Water Company's Fall Creek water diversion. Fortunately, the District's surface water diversions are located high in tributary headwaters, are inoperative in drought years, and lose surface flow in mid- to late summer in all but the wettest years.

Figure A.18. Bedrock scoured pool in the middle San Lorenzo River.



Alley 2005

Bedrock scoured pool in the middle San Lorenzo River, with fastwater feeding habitat for salmonids (run then riffle), emptying into a pool .

A.5.1.c The lower mainstem.

With large granite boulders in abundance, the lower mainstem resembles many Sierra Nevada streams. The lower mainstem has much greater spring and summer baseflow than upstream, to create relatively higher food abundance, even in summer. Zayante Creek, draining a sub-watershed that is approximately ¼ of the total watershed area, enters the lower mainstem. Many juvenile steelhead reach smolt size after one growing season every year in lower mainstem. As the river flows through Henry Cowell Park and the canyon gorge, its gradient increases greatly. Through the gorge, there are deeper, fastwater riffles, and more step-runs and runs, which provide good fastwater feeding habitat for juvenile steelhead. The lower mainstem was a major contributor to the adult steelhead index in 2001 (Table A.6). Passage for spawning adult steelhead and coho salmon can be difficult through the gorge in drier winters because of boulder cascades and a wide riffle in the Rincon. Spawning habitat is poor due to high sand content in spawning glides.

After Santa Cruz was built on the alluvial floodplain, wetlands were filled in and built over, and the river's width was narrowed. Downtown Santa Cruz was built on the old river channel. After the 1955 flood, the Army Corps of Engineers built a levied flood control channel for the lower San Lorenzo River, and a concrete channel with vertical walls along lower Branciforte Creek, which joins the river near its mouth. The river is now confined to this narrow, straightened channel. Without wide, intact wetlands and riparian woodlands, the confined stream channel is prone to sedimentation and high stormflow damage. Quiet backwater refuges for fish, once present during stormflows, have been eliminated. The simplified channel facilitates large mammal predation of migrating fish. Recently, the City has attempted to increase habitat complexity within the flood control channel, retaining more riparian vegetation, and forestalling dredging.

A.5.1.d Tributaries

Tributaries entering the upper and middle mainstem from the west (Boulder, Clear and Fall creeks) contribute granite-based substrate, and are relatively steep, as they drain from Ben Lomond Mountain. Tributaries entering from the east (Kings, Bear, Love, Newell and Zayante-Bean creeks) contribute sandstone and shale-based substrate, and are relatively low gradient. The Branciforte-Carbonera creeks contribute granite-based substrate to the San Lorenzo estuary/ lagoon. These tributaries are low gradient in their lower reaches and increase in gradient upstream. Hence, they are more accessible to adult steelhead and coho salmon (if they can negotiate the Branciforte flood control channel). Spawners need not maneuver the San Lorenzo gorge and Felton Dam fish ladder to reach spawning habitat.

Following are short descriptions of each tributary and its aquatic habitat conditions, beginning at the upper mainstem and moving downstream:

Kings Creek has some of the poorest steelhead habitat in the watershed, due to high sedimentation, low spring and summer baseflow, very poor spawning habitat and very limited rearing habitat leading to slow juvenile growth. It contributed only 3.8% to the adult index in 2001 though approximately 6.5% of its length has steelhead habitat. There is anecdotal evidence of coho using the creek in the late 1950s. This tributary contributes considerable sediment to the mainstem. Much sedimentation has occurred concurrently with active logging operations, road erosion, and landsliding. The District completed watershed enhancement projects, including reconfiguring a badly gullying and eroding CDF fire road and removing a concrete wall (remnant of a dam) that was causing streambank erosion. The County reworked the road paralleling the creek. A significant landslide still exists in the Logan Creek drainage, where a road crosses near its base, increasing sediment loads into the creek (Alley et al., 2004a).

Bear Creek is a low gradient, well-shaded tributary that contains many deep, bedrock corner pools and long riffles. However, it has limited cover in pools due to a lack of large wood. Deeper runs offer some yearling habitat when less embedded, but pools are primary habitat. Sedimentation is high in wet winters, such as 2005-2006 (Alley pers. Observation, 2006), it being contributed by significant landsliding in the headwaters and Deer Creek. Rural roads and logging accentuate erosion problems. Bear Creek is a productive steelhead stream, contributing 10% to the adult index in 2001 (Table A.6), though juvenile growth is slow due to low spring and summer baseflow.

Boulder Creek's canyon downstream of the Boulder Creek Country Club, with its steep vertical walls, has some of the most ruggedly beautiful and inaccessible stretches in the entire watershed. The creek's streambed is dominated by large granitic cobbles and boulders in turbulent riffles and runs, and is punctuated with relatively deep pools containing virtually no instream wood. The stream has relatively high winter stream velocities through a very confined, heavily shaded canyon. High winter water velocities wash out large wood, and pools often have little cover except from depth and large, unembedded boulders. Overwintering juveniles are more easily flushed out of Boulder Creek than other tributaries. Course sand deltas are sometimes found at the confluences of its steep tributaries. Spawning habitat is limited, and steep boulder riffles may restrict adult passage in drier years. Resident rainbow trout likely inhabit the upper canyon along with steelhead. Summer water temperature is some of the coolest in the watershed. Low spring and summer baseflow are limiting factors, and juvenile steelhead growth is slow. Steelhead are probably unable to pass through a bedrock chute above the Boulder Creek golf course, across from the Kings Highway junction with Big Basin Way.

Newell Creek has a mile of easily accessible steelhead habitat below a bedrock chute that is likely a passage impediment at flows less than approximately 300 cfs (Alley, 1993; Alley et al. 2004). Winter spawning flows are likely much reduced until Newell Creek Dam spills in winter. The only restriction on releases from the City of Santa Cruz storage reservoir is a minimum flow release of 1 cubic feet per second. This flow is probably above natural levels in summer, but well below natural levels during the important spring months when juvenile steelhead growth is normally highest. Steelhead growth was slow in Newell Creek in 2001 (Alley, 2002). Since winter releases may not mimic natural winter stormflow, spawning habitat may be quite limited when adult steelhead are ready to spawn. YOY densities were moderate and yearling densities were relatively low in 2001 compared to other tributaries (Alley, 2002). The streambed is generally clean, with sediment being retained behind the dam. However, embeddedness of cobbles was high due to lack of flushing flows in 2001 (Alley, 2002). The riparian corridor is well developed and diverse, despite houses being relatively close to the stream in places.

Fall Creek is one of the most shaded and coolest tributaries in the watershed. Even though much of the creek is within Henry Cowell Park, it is subject to large sediment inputs from steep hillslopes prone to landsliding. The landscape is apparently still recovering from past clear-cut logging and limekiln operations. The stream gradient is steep with few pools. The stream is dominated by shallow, fast riffles. Juvenile steelhead growth is very slow despite relatively high summer baseflows. Steelhead are limited by poor pool development, a highly sedimented streambed, and heavy shading. The District water diversion and fish ladder at the lower end of the creek (recently acquired from California-American Water) may cause passage difficulties, should the fish ladder become damaged by high flows.

Zayante Creek and its tributary Bean Creek both pass through a very erosive landscape. They both have long extensions at a low gradient. They are significant contributors to the juvenile steelhead population and adult index (Zayante Creek = 13.5%; Bean Creek = 10%). Lower

Zayante Creek, downstream of the Bean Creek confluence, receives heavy sediment inputs from Bean Creek, but supports relatively high growth rates for juvenile steelhead in wetter years with higher spring/summer baseflow. Still, juvenile densities are typically low. Above the Bean Creek confluence, fish passage improvements on Zayante Creek have been made over a bedrock shelf at the Mount Hermon dam abutment. Between the dam abutment and the Lompico Creek confluence, long pools dominate the stream. A series of bedrock shelves at the tails of pools are followed by short, bedrock riffles emptying into the next pool. Stream shading is moderate. Instream wood and overhanging vegetation provide good cover. Quarries west of Quail Hollow Road deliver chronic supplies of sand to Zayante Creek, upstream of the Trout Farm Inn (Alley, pers. observation). The Trout Farm Inn pond is a source of bullfrogs to the creek. An unusually designed fish ladder was constructed at a modified bedrock shelf under Quail Hollow Road Bridge. A bedrock chute approximately ½ mile upstream of the bridge had a narrow channel cut through it to improve passage. Upstream of Lompico Creek, stream gradient increases and step-runs become ¼ of the habitat (Alley, 2002). This is a high producer of larger yearling steelhead that inhabit primarily pools. A 5-6 foot high bedrock, chute located downstream of Mountain Charlie Gulch, likely causes a low-flow adult passage impediment during dry years and drought (Alley pers. observation). This stretch is subject to periodic high sediment input. Logging was active in the Mountain Charlie drainage by the City of Santa Cruz in the past, accelerating erosion rates from disturbance caused by skid trails and logging roads (Alley pers. observation). The headwaters have experienced recent vineyard development to hasten soil erosion. Despite higher streamflow than other tributaries, low summer streamflow limits fish habitat (Ricker and Butler, 1979) along with streambed sedimentation. The extent of steelhead distribution includes some of Mountain Charlie Gulch and Zayante Creek beyond the Mountain Charlie confluence an unknown distance. However, in 1981, Mountain Charlie Gulch and Zayante Creek above its confluence were dry in fall (Smith 1982; Alley, pers. observation).

Bean Creek near Mount Hermon is extremely sediment-laden and landsliding is common during heavy storms. Pool development and spawning habitat are poor. Heavy foot traffic from Mount Hermon visitors, both in the channel and streamside, has degraded summer habitat. Small rock dams limit fastwater habitat and insect production. A large, active landslide chronically introduces sand to the channel near the quarry opposite Locatelli Lane. A short, periodically very productive steelhead reach exists from the Mt. Hermon Road, cutoff upstream beyond Lockhart Gulch to Ruins Creek. The riparian corridor has been healthy until recently with good pool cover provided by instream wood in a meandering reach. This reach is now seriously threatened by recent land development in the riparian corridor. It has resulted in riparian clearing and destructive streambank stabilization practices intended to protect new houses constructed on low-lying property close to the stream. This stretch has been chronically subjected to instream wood-clearing and periodically substantial sedimentation, as well. Upstream of Ruins Creek, streamflow fell off in short order and, at varying distances from year to year, the stream channel becomes dewatered upstream. In 2004, the dewatered reach extended 9,350 feet upstream past the Mackenzie Creek confluence (Alley, 2005). Estimated streamflow upstream of there was only 0.02 cfs, with steelhead restricted to pool habitat only. This was the low gradient, cool-water reach where coho salmon juveniles were captured and released in 2005 (Alley, 2006). Thus, surface flow in upper Bean Creek is extremely vulnerable to well pumping in the Santa Margarita aquifer to the northwest of Scotts Valley. Steelhead growth is slow and limited by low spring and summer baseflow.

Carbonera Creek is the other tributary that drains out of Scotts Valley to the south, emptying into Branciforte Creek in northern Santa Cruz near Highway 1. Steelhead adult passage in Carbonera Creek is stopped at Moose Lodge Falls behind the Moose Lodge adjacent to Highway 17. The steelhead reach flows through a deep canyon dominated granite-based streambed cobbles and sand, with primarily redwood and tanoak on the steep sideslopes. In the higher gradient reach below the falls, short pools, step-runs and runs dominate the stream. Riffles are scarce. A population of predacious green sunfish was detected in the creek in the mid-1990s, escapees from ponds on Camp Evers Creek in Scotts Valley (Alley, 1997). Summer water temperature is cool, but summer baseflow is limiting and very low. Therefore, juvenile steelhead growth is very slow, but yearling densities were relatively good in 2001 and higher than 12 of 20 sampled tributary sites in 2001 (Alley, 2002). This was because pools were relatively deep and cover was provided primarily by unembedded boulders. The lower reach of Carbonera Creek was lower gradient, badly sand-dominated and subject to substantial sedimentation that limited steelhead habitat. Escape cover and pool scour were completely reliant on instream wood. Yearling densities there were relatively low and steelhead growth was very low, resulting from limiting low streamflow (Alley, 2002). Carbonera Creek contributed 4.3% to the adult index in 2001.

Branciforte Creek has a long, low-gradient reach between the flood-control channel and Granite Creek confluence. Shallow pools dominated more than two-thirds of the stream channel below Granite Creek, with escape cover primarily provided by undercut banks, overhanging vegetation and instream wood. Food was likely in very short supply with bedrock-dominated riffles and low spring and summer baseflow. As gradient increases in Branciforte Creek above Granite Creek, pools shorten (remain mostly shallow except at corner pools) and step-runs increase. Juvenile steelhead inhabit pools where escape cover was provided by unembedded boulders, hanging root masses along the stream edge and undercut banks. Increased step-runs with coarse granitic cobbles offered better aquatic insect habitat.

Several dam abutments with narrow openings between walls are present in the reach above Happy Valley School and may pose passage problems if they collect instream wood, as occurred in 2005 (Alley, 2006). Occasional old-growth redwoods remain creekside in patches, providing streambank stability and undercut banks. A drop structure creates a passage impediment near the Tie Gulch confluence (Alley et al., 2004a). A significant stream diversion existed upstream, adjacent to the junction of Vine Hill and Jarvis Roads in 2003 (Alley, pers. observation). Low spring and summer streamflow, summer water diversion, high sand content of the streambed and man-made passage impediments are limiting factors to juvenile steelhead in Branciforte Creek.

A.6 Limiting factors to steelhead survival in the San Lorenzo River

This section identifies and discusses the factors that limit the chances of steelhead survival in the San Lorenzo River.

The primary limiting factors to fishery productivity in the watershed are those that impact rearing habitat for juveniles (Ricker and Butler, 1979; Smith, 1982). Rearing habitat includes the following characteristics:

- Adequate flows for pool development and to provide fastwater feeding stations for fish

- Escape cover such as undercut banks, rootwads, large instream wood, unembedded cobbles and boulders, surface turbulence, and submerged or overhanging vegetation or debris
- Aquatic and terrestrial insects for food
- Suitable water quality conditions, including water clarity, water temperature, dissolved oxygen concentrations and contaminant levels (Smith, 1982).

Table A.7 lists the factors that affect rearing habitat quality on the San Lorenzo River.

Table A.7. Limiting factors affecting rearing habitat quality variables on the San Lorenzo River

Limiting factors		Habitat quality variable
Primary	Secondary	
Excessive fine sediment	Streamflow	Food availability
Streamflow	Shortage of large woody material	Fast water feeding areas
Excessive fine sediment without large woody material for scour	Streamflow	Escape cover
Excessive fine sediment without large woody material for scour	Streamflow	Adequate water depth
Excessive fine sediment		Water clarity
Absence of closed riparian canopy	Streamflow	Water temperature

Source: Alley et al., 2004a.

Table A.8 ranks limiting factors by relative importance for the mainstem of the San Lorenzo River and its major tributaries.

Table A.8. Assessment of limiting factors for the San Lorenzo River and major tributaries.

Location	Sediment		Adult Passage Impediments	Streamflow	Water Temperature
	Spawning	Rearing			
Lower River Except Gorge[1]	⬤	⬤	•	⬤	⬡
Lower River Gorge	●	⬤	●	•	○
Middle River[1]	•	⬤	•	⬤	○
Upper River	•	⬤	•	○	
Branciforte	◦	⬤	●	○	
Carbonera	•	⬤	◦	●	
Zayante	•	⬤	●	●	
Bean	•	⬤		⬤	
Lompico		⬤	⬤	⬤	
Fall		⬤	•	•	
Newell			○	●	●
Love		⬤		○	
Boulder		⬤	◦	⬤	
Bear		⬤	●	●	
Two-Bar		⬤	●	○	
Kings	•	⬤	•	⬡	

⬡ – Highly Limiting, ○ – Moderately Limiting, ◦ – Minimally Limiting, Blank – Not Limiting. Closed circles denote where enhancement actions could be effective (see Recommendation Section).
1 – Fry abundance in the lower and middle River may depend heavily on spawning in upstream tributaries.

Source: Alley et al., 2004a.

A more detailed discussion of the following limiting factors follows:
- Streambed sedimentation
- Reduced stream flows
- Decreases in instream wood
- Barriers to anadromy

A.6.1 Streambed sedimentation

Sedimentation is one of the principal limiting factors for salmonid populations in the San Lorenzo River. Background sedimentation is a natural part of the river, which is greatly increased from upland human activities.

Sedimentation affects every salmonid life stage within the freshwater environment. Fine sediment reduces water percolation through spawning gravels, impacting survival of salmonid eggs and emerging fry. Fine sediment impacts juvenile rearing habitat by reducing pool depth, and burying boulders and cobbles that juveniles may hide under. Cobbles must be 25% or less embedded before they may provide escape cover for smolt-sized juveniles.

Loss of cracks and crevices between cobbles in riffles decreases aquatic insect habitat and reduces food availability for salmonids. Water turbidity associated with sedimentation also impacts salmonid feeding capability. Salmonids are visual feeders, and need clear water to see their drifting prey. The longer the stream remains turbid after a storm in spring (the most important feeding season for juveniles in small coastal watersheds), the less feeding time available to juvenile salmonids. Thus, turbidity can greatly reduce growth rate.

Sedimentation can affect adult upstream migration by making pools more shallow. In order to migrate upstream past instream barriers, salmonids need adequate pool depth below the barrier in order to jump over it. Adult steelhead generally require these approach pools to be at least as deep (some say twice as deep) as the barrier is high, for a successful jump.

The San Lorenzo River Watershed Management Plan (County of Santa Cruz, 1979) described the effects of excess sediment on fisheries within the watershed:

> Excessive sediment in spawning areas has been found to reduce the number of fish emerging from spawning gravels by up to 85% (Shapovalov and Taft, 1954). Observations of insect production on streams of the San Lorenzo River watershed show biomass to be 75-90% lower on silted reaches of Bean, Zayante, and Carbonera Creeks as compared to the upper San Lorenzo River. Where the rocks became completely surrounded by sand, researchers in Idaho found that the number of young fish that could be supported was reduced by 90% (Bjorn, 1977). Excessive sedimentation is widespread in the streams of the San Lorenzo River watershed. The Department of Fish and Game surveys on the main river show that the percentage of bottom classified as silt measured from 8% in 1966 to 65% in 1972. The amount of gravel present dropped from 20% to 2% (Lang, 1972). Other surveys have pointed out the presence of excessive amounts of silt in all of the tributaries but the relatively undisturbed Fall Creek.

Alley et al. (2004) found that in the middle mainstem, the El Niño high stormflows of winter 1997-98 caused significantly increased embeddedness of cobbles in 1999 (impact delayed a year for sediment to reach the mainstem), compared to 1995 streambed conditions. This increased embeddedness was correlated with decreased juvenile steelhead densities. However, other factors played a part, including substantially higher baseflow during the spring and summer of 1995 compared to 1999. The higher streamflow would also increase juvenile survival and cause more rapid growth rate.

Embeddedness is a very poor predictor of steelhead densities and growth rate in the middle and lower mainstem San Lorenzo River. Streamflow (which affects insect drift rate, habitat depth and often surface turbulence as cover in fastwater habitat) is a good predictor of steelhead densities and especially growth rate in the middle mainstem (Reaches 6-9). In 2007, riffle and run embeddedness was much lower in the middle mainstem (18–34%) compared to 1995 (30–45%) and 1999 (43–48%). Yet smolt-sized steelhead densities were less in 2007 than 1999 at 4 of 5 comparable sites in the lower and middle mainstem San Lorenzo River (Alley, 2008). The critical limiting factor was that streamflow was much lower in 2007.

A.6.2 Decreased stream flow

Decreased stream flow is another principal limiting factor for salmonid populations in the San Lorenzo River.

Adequate winter streamflow is critical for salmonid survival in the following ways:

- Enables fish passage to spawning sites
- Maintains healthy spawning habitat
- Flushes out excess sediment

Adequate winter streamflow is needed to allow adult fish passage to spawning sites, which typically improve in quality nearer the headwaters. Instream flow studies (Alley, 1993; Ricker and Butler 1979) indicate that optimal spawning habitat (in the lower mainstem above the gorge, and in the gorge) occur in the 70-100 cubic feet/second (cfs) range. Therefore, water diversions and well pumping in November, when estimated mean monthly streamflow is 53.8 cfs, and in December when it is 107.9 cfs, may adversely affect these optimal spawning conditions (Alley, 2004).

Adequate winter streamflow is also necessary to flush deleterious sediment out of the system to maintain healthy spawning and rearing conditions.

During drought, fish passage is more difficult, and water diversion during these periods exacerbates the problem, by further reducing surface flow, dewatering the channel, and elevating water temperature. These conditions lead to poor spawning success and reduced rearing habitat. For example, when the Felton Diversion Dam above the steep San Lorenzo River gorge became operational, just prior to the 1976-77 drought, adult steelhead were found stranded in Henry Cowell Park, as reported by Shappel, a CDFG biologist.

In the dry season, adequate summer streamflow (baseflow) is crucial to maintain proper water temperature, ample food supply and adequate rearing habitat for coho and steelhead. Ricker and Butler (1979) used IFG4 and HABTAT models to estimate habitat availability as a function of instream flow within the watershed. They found that, while winter streamflows could exceed instream flow needs of coho and steelhead, summer streamflows were always well below the optimal rate for habitat needs. Ricker and Butler (1979) concluded that any further decrease in streamflow would reduce habitat. For example, they estimated that, for the San Lorenzo River below Boulder Creek, a 50 percent flow reduction (from 3 cfs to 1.5 cfs) resulted in a 60 percent reduction in rearing habitat.

Decreased streamflow due to drought conditions or water extraction may create new passage barriers for fish, or make existing ones more difficult for fish to jump over. For a more complete discussion of this topic, refer to the following section "Barriers to anadromy".

Reduced streamflow reduces spawning habitat in both winter and spring; it reduces rearing habitat in spring, summer and fall. Reduced streamflow means reduced water depth, slower water velocity, fewer feeding areas, less food availability, less escape cover, and less surface turbulence (which acts as cover and oxygenates the water). Reduced streamflow may, at the same time, increase water temperature in the less shaded reaches. Adequate stream flow is necessary to transport sediment, to scour pools, to recruit spawning gravel and large instream wood, to clean riffles of fine sediment, and to enhance fish cover and insect production.

Ricker and Butler (1979) used IFG4 and HABTAT models to estimate habitat area as a function of streamflow in the San Lorenzo River watershed. They found that natural streamflows exceeded instream flow needs of steelhead and coho salmon only during wet winter months. They reported that during the summer, flows were always well below the optimum level for habitat needs. Ricker and Butler (1979) concluded that any further decreases in flow would lead to a direct reduction in habitat. Generally, they found that the percent of habitat loss was greater than the percent reduction in streamflow. They found that in the San Lorenzo River below Boulder Creek, a 50% flow reduction from 3 cfs to 1.5 cfs resulted in a 60% reduction in habitat from 2,500 ft^2 habitat/1000 ft of stream length to 1,000 ft^2 habitat/1000 ft. During dry years, total spawning habitat in the watershed may be reduced by as much as 70%, and total summer nursery habitat may be reduced by 50%. This may occur on average, once every 10 years (Ricker and Butler, 1979).

In coastal streams, downstream smolt migration may be stopped during drought if the stream goes dry before the migration is finished.

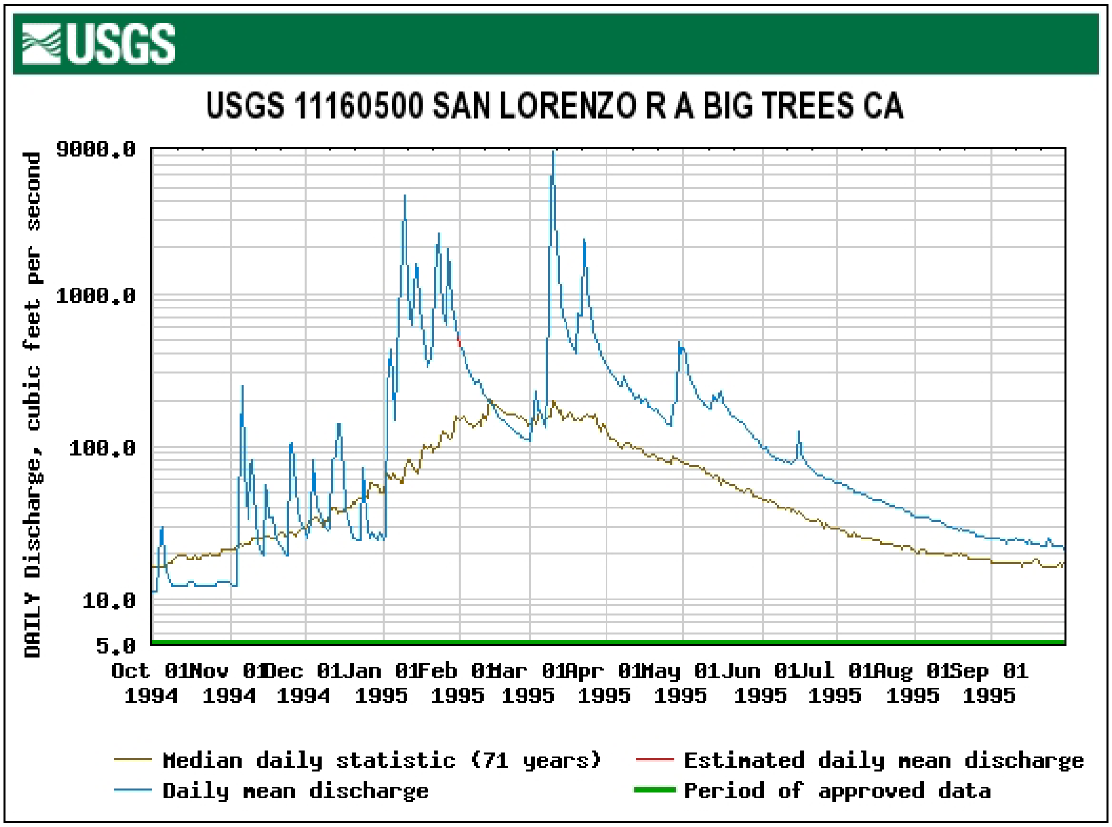
A.6.2.a Municipal water extraction and well-pumping

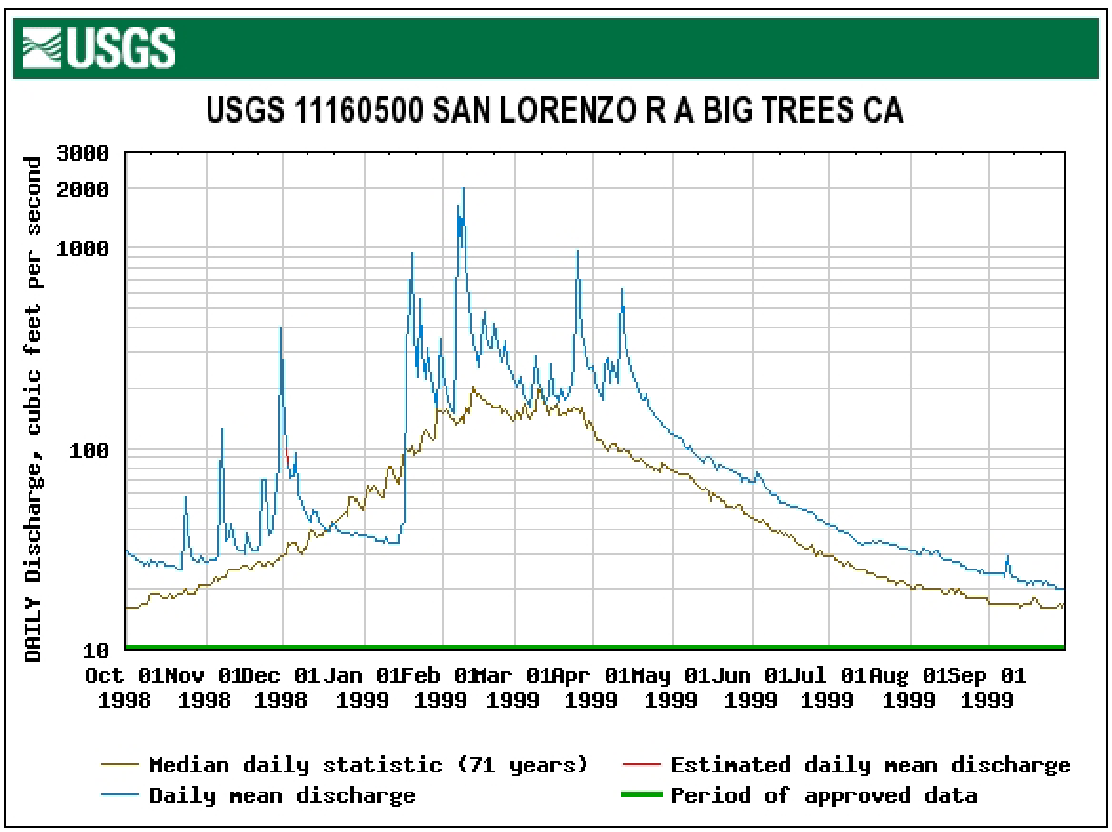
Increased water extraction for municipal supply has caused aquatic habitat loss from reduced streamflow.

Table A.9 summarizes information in the hydrographs beneath it.

Table A.9. A comparison of streamflows on the San Lorenzo River in 1995 and 1996

Date	Streamflow at Big Trees Gage, 1995	Streamflow at Big Trees Gage, 1999
1 April	~320	~210
1 May	400+	~120
1 June	~100	~70
1 July	~55	~32
1 August	~34	~31
1 September	~24	~24


USGS
USGS 11160500 SAN LORENZO R A BIG TREES CA
DAILY Discharge, cubic feet per second
9000.0
1000.0
100.0
10.0
5.0
Oct 1994
01Nov 1994
01Dec 1994
01Jan 1995
01Feb 1995
01Mar 1995
01Apr 1995
01May 1995
01Jun 1995
01Jul 1995
01Aug 1995
01Sep 1995
01
Median daily statistic (71 years)
Daily mean discharge
Estimated daily mean discharge
Period of approved data


USGS
USGS 11160500 SAN LORENZO R A BIG TREES CA
DAILY Discharge, cubic feet per second
3000
2000
1000
100
10
Oct 1998
01Nov 1998
01Dec 1998
01Jan 1999
01Feb 1999
01Mar 1999
01Apr 1999
01May 1999
01Jun 1999
01Jul 1999
01Aug 1999
01Sep 1999
01
Median daily statistic (71 years)
Daily mean discharge
Estimated daily mean discharge
Period of approved data

Streamflow did not become similar until August between years, allowing faster growth rate in 1995. Furthermore, since most salmonids and insects are in fastwater habitat in these reaches, comparisons of embeddedness in pools is irrelevant to juvenile numbers. Additionally, there was only modest increase in embeddedness in 1999 in 3 of the reaches and no increase in Reach 9. No comparisons of percent fines were possible. The decrease in the fish population estimate in 1999 was likely due primarily to less streamflow in 1999 and a change in censusing methods that included better censusing of low-density pools in 1999 and not increased embeddedness.

> Embeddedness is a very poor predictor of steelhead densities and growth rate in the middle and lower mainstem San Lorenzo River. Streamflow (which affects insect drift rate, habitat depth and often surface turbulence as cover in fastwater habitat) is a good predictor of steelhead densities and especially growth rate in the middle mainstem (Reaches 6-9). In 2007, riffle and run embeddedness was much lower in the middle mainstem (18–34%) compared to 1995 (30–45%) and 1999 (43–48%). Yet smolt-sized steelhead densities were less in 2007 than in 1999 at 4 of 5 comparable sites in the lower and middle mainstem San Lorenzo River The critical limiting factor was that streamflow was much lower in 2007 (Alley, 2007).

Analysis of daily flow data at the Big Trees stream gage indicates that the mean and minimum streamflow for October have shown a 17.2% and 32.1% decrease, respectively between 1937 and 1997 (Alley et al., 2004a). This is likely due to water extraction from both surface diversions and well pumping in addition to a possible reduction in late season rainfall (Alley et al., 2004a). In addition, mean and maximum streamflow in December has decreased 36.2% and 46.2%, respectively (Alley et al., 2004a). Well pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased (Alley et al., 2004a). The capture of early runoff in Loch Lomond before it spills would also partially contribute to the reduction after 1960.

The complete dewatering of the lower San Lorenzo above Highway 1 occurred in the mid-1970s and 1988 resulted from the Santa Cruz City Water Department's water diversion at Tait Street. The drying of the channel occurred only for a short distance, and streamflow resumed downstream. However, the reduced streamflow formed a complete passage barrier. Such an occurrence would be the most critical during downstream smolt migration from March through May. During these months, a complete dewatering of the lower channel or early closure of the river mouth could occur during drought conditions (Alley et al., 2004a). Such an occurrence could kill or prevent smolt-sized fish from entering the ocean, leaving them in poor habitat conditions, and susceptible to predation.

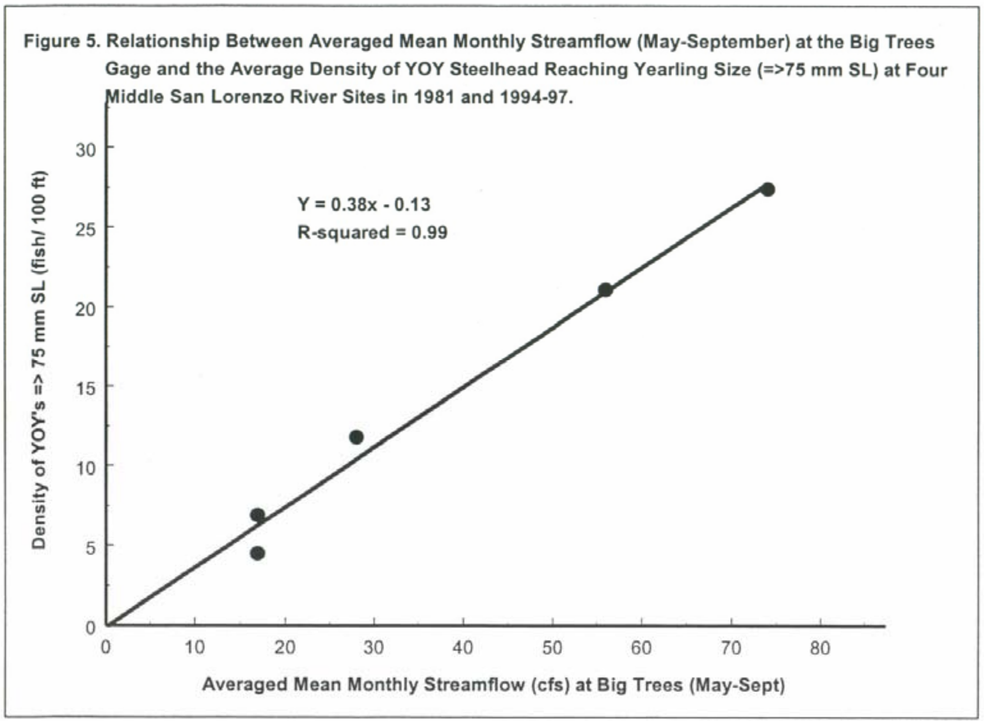
The San Lorenzo River Salmonid Enhancement Plan (Alley et al., 2004a) addressed groundwater extraction as a significant, yet difficult to track, source of flow reduction. Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation. It is estimated that overdraft of the Scotts Valley groundwater basins has reduced summer baseflows to the creeks draining the area underlain by the Santa Margarita. These reductions significantly impact rearing conditions for juvenile steelhead by reducing baseflow during the critical summer months.

A.6.2.b Stream flow & steelhead densities in the San Lorenzo River

Alley et al. (2004) analyzed the relationships between stream flow and local steelhead populations. Figure A.19 illustrates the positive relationship between average mean monthly streamflow (May-September) and the density of YOY steelhead reaching smolt size. Figure A.20 illustrates the positive relationship between the minimum daily streamflow in September and the overall density of smolt-sized juveniles in the middle mainstem. Figure A.21 shows the positive relationship between minimum daily flow in September and the density of YOY steelhead in tributary streams. Figure A.22 shows the linear relationship between annual minimum streamflow and YOY steelhead density in Boulder Creek.

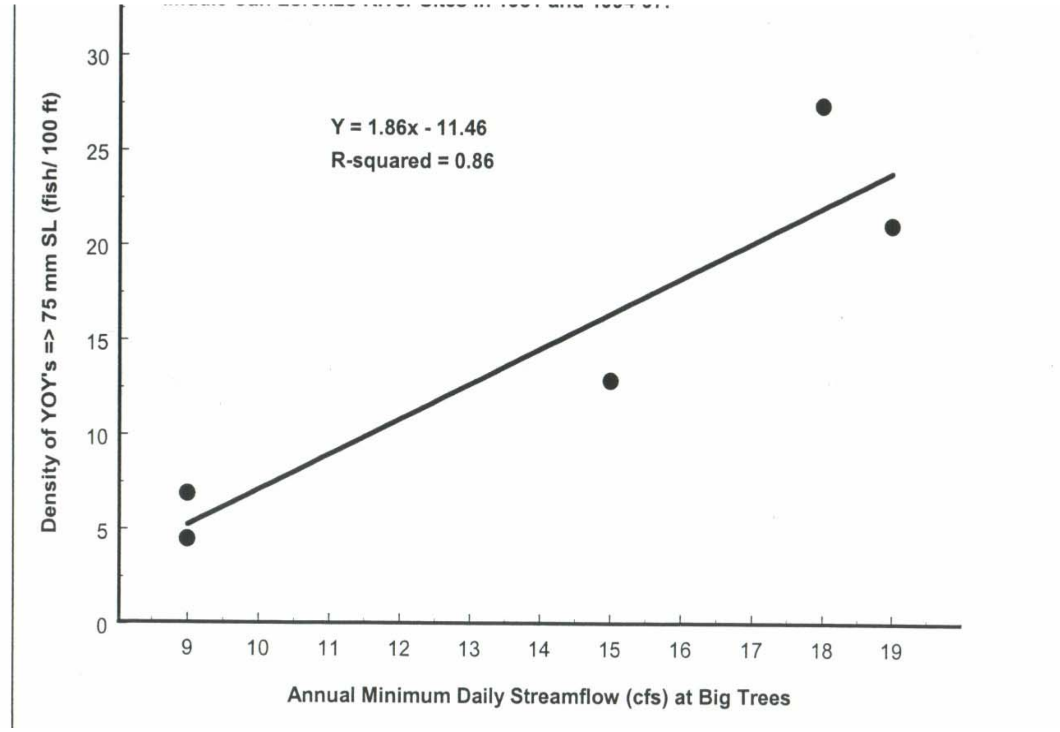
Table A.10 summarizes the combined results of Alley's analyses (Alley et al. 2004a). For all four middle mainstem sites combined, in a dry year (1994), there was a 27% reduction in density of YOY steelhead reaching smolt size and a 17% reduction in total smolt-sized steelhead juvenile density due to water extraction. In a wet year (1995), the reductions were 9% and 6%, respectively, due to water extraction rates. The middle mainstem is downstream of District water diversion points. On Zayante Creek, the percent reduction in YOY densities caused by water extraction was 19% (1994) in a dry year and 9% in a wet year (1998). In lower Boulder Creek below District water diversions, YOY densities were reduced by 28% in a dry year (1994) and 24% in a wet year (1998) due to water extraction. These analyses indicated that water extraction has a measurable (with high correlation coefficients), negative impact on steelhead growth rates in the middle mainstem and YOY densities in San Lorenzo tributaries. (Ricker, 1979).

Figure A.19. Linear relationship between mean monthly streamflow at the Big Trees Gage and fall density of yearling (smolt-sized) juvenile steelhead in the middle mainstem San Lorenzo River.



Source: Alley et al. 2004.

Figure A.20. Linear relationship between annual minimum daily streamflow at Big Trees gage and fall density of yearling (smolt-sized) juvenile steelhead, in the middle mainstem San Lorenzo River.



Source: Alley et al. 2004.

Figure A.21. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Boulder Creek.

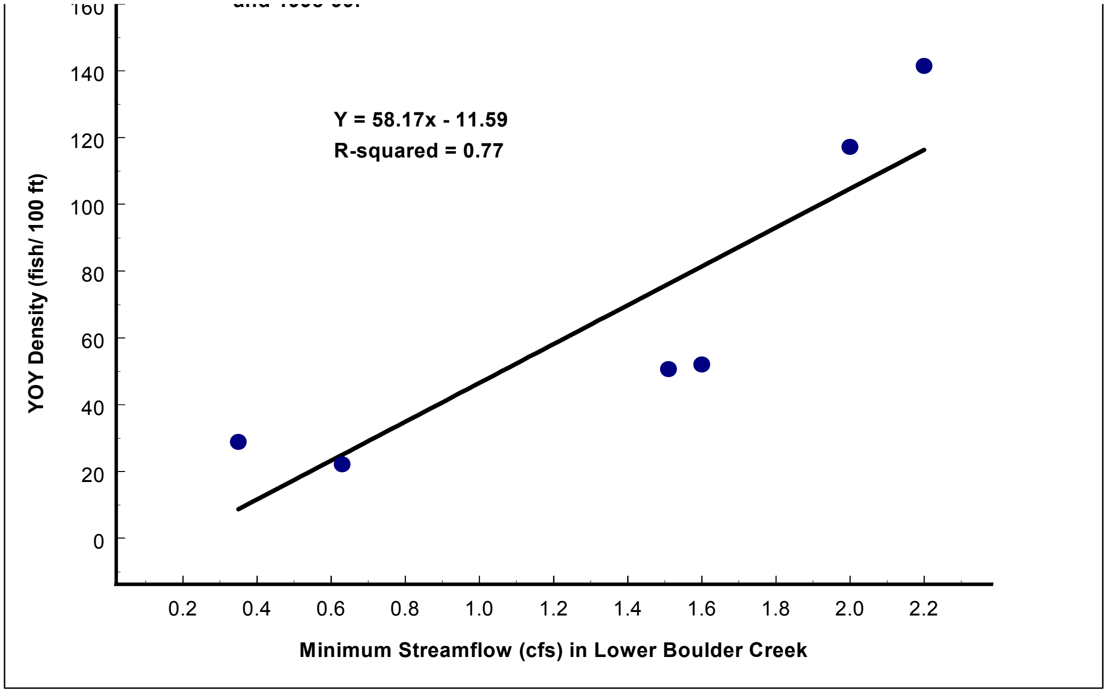
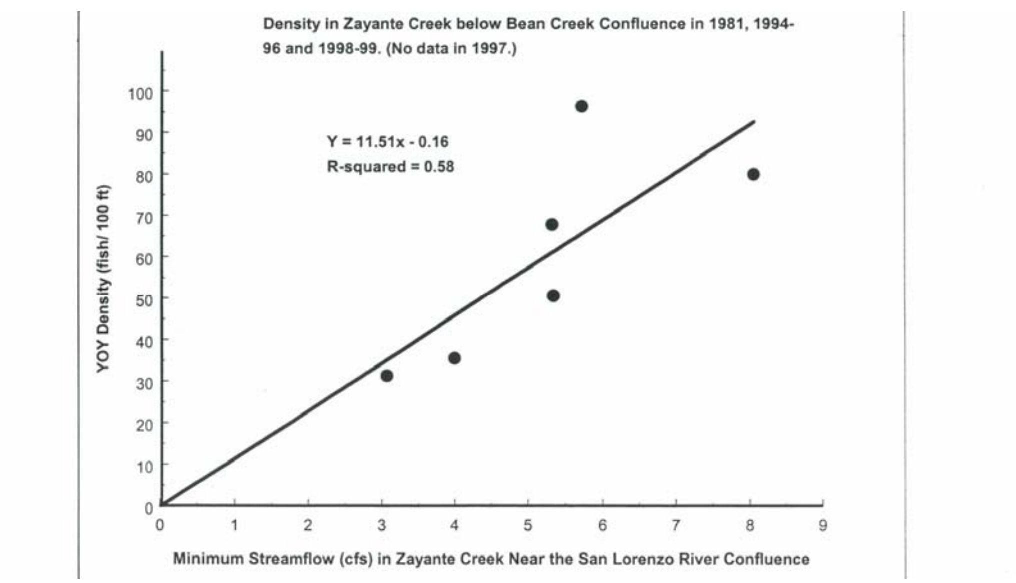
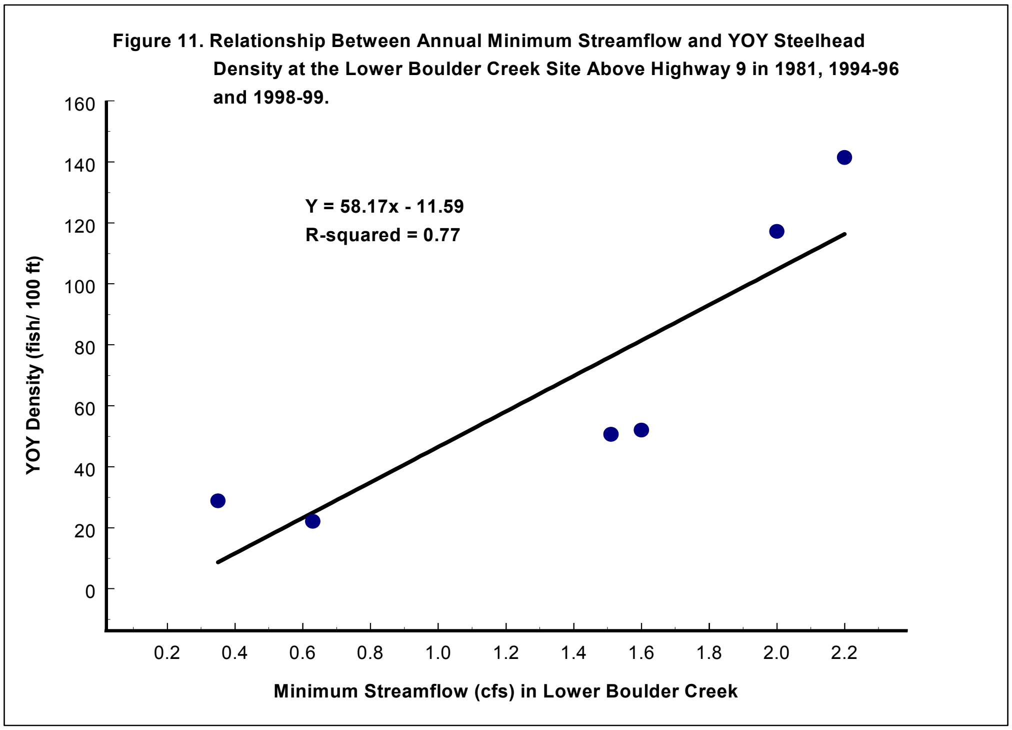


Figure A.22. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Zayante Creek.



Source: Alley et al. 2004.

Figure A.23. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Boulder Creek.



Source: Alley et. al. 2004.

Table A.10. Estimated instantaneous flow extractions in September and associated estimates of reduced density for yearling-sized young-of-the-year fish (YOYs) at mainstem river sites and reduced total YOY density at tributary sites. (Alley et al., 2004a).

Site		Annual Minimum Flow cfs. Wet/Dry Year Wet Year ('95) Extraction (%) Dry Year ('94) Extraction (%)	Correlation Coefficient (R2) of Linear regression of flow to fish density*	Estimated % Reduction of Age/Size Category due to Water Extraction and Estimated Density with Unimpaired flows (fish/ 100 ft)*			
				YOY's => 75 mm SL		All Juveniles => 75 mm SL	
				1994 dry	1995 wet	1994 dry	1995 wet
Middle River	4-Site Composite	18 / 9 1.51(_9_%) 1.35 (8%	0.86 (YOY=>75mm to annual min. Flow at Big Trees)	27% (9.4)	9% (30.2)	17% (14.4)	6% (44.3)
	Below Fall Creek	14.6 / 5.1 0.9 (6%) 0.8 (16%	0.85 (YOY=>75mm to annual min. Flow at Big Trees)	13% (6.2)	8% (11.8)	12% (6.8)	5% (19.7)
	Ben Lomond	5.8 / 2.5 0.36(6%) 0.2 (8%)	0.89 (YOY=>75mm to annual min. Flow at Big Trees)	22% (12.2)	7% (65.8)	11% (25.4)	5% (90.6)
	Brookdale	4.6 / /1.8 0.36 (8%); 0.2 (11%))	0.87 (YOY=>75mm to annual min. Flow at Big Trees)	36% (4.7)	10% (29.4)	15% (11.7)	8% (40.0)
	Below Boulder Creek	4.2 / 1.1 0.26 (6%) 0.15 (14%)	0.42 (YOY=>75mm to annual min. Flow at Big Trees)	3% (10.0)	3% (11.8)	2% (17.8)	1% (23.0)
Estimated Flow: Wet (1998) Dry (1994) Average Extraction (% reduction)				1994 (dry) YOY's	1998 (wet) YOY's		
Lower Boulder	Above Hwy 9	2.2 / 0.6 0.26 (12-43%)	0.77 (Total YOY to Minimum Measured flow)	28% (30.9)	24% (186.3)		
Bean Creek	Below Lockhart Gulch	6.7 / 2.1 0.5 (7 – 24%)	0.59 (Total YOY to Mean summer flow@ Mt. Hermon)	67% (42.3)	20% (132.7)		
Zayante Creek	Below Bean Creek	8.8 / 3.8 0.65 (9-17%)	0.58 (Total YOY to Minimum Measured flow)	19% (38.8)	9% (87.5)		

* Regressions were developed from density estimates at historical sampling sites within reaches, and estimated reductions in fish densities may not be directly extrapolated to entire reaches. However, the significant correlation coefficients (>= 0.7) indicate that there is a meaningful direct linear relationship between flow and fish density at those sites. Based on available data, the relationship is less direct in other sites downstream of the Zayante Creek confluence with lower correlation coefficients.

A.6.3 Absence of large instream wood

The benefits of instream wood are discussed in Chapter 3. The shortage of instream wood in the San Lorenzo River watershed is the result of logging, development, and logjam removal policies and practices.

Due to clear cutting during from the late 1800s through the 1970s, and continued cutting of large trees along streams, a century has passed with little input of large instream wood. Large, second-growth trees adjacent to streams could be a significant source of large instream wood, but they are also valued as timber. Most of the watershed's streams are lined with roads and houses. Trees are often cleared around homes. The resulting loss of riparian forest greatly reduces the natural rate of input of large instream wood.

Throughout the watershed, much instream wood is removed from streams. The County historically had an active logjam removal program, and continues the program in consultation with the CDFG. The County continues to remove instream wood when it directly increases the risk of flood or property damage in the more developed areas of the watershed, and in response to complaints from streamside residents (Kristen Schroeder Kittleson, personal communication to Alley). However, the County has no permit from NOAA Fisheries for their instream wood activities (Alley, 2006). Liability issues have not been resolved (Alley, 2006).

Despite the intention of protecting public safety, removal of large instream wood accumulations in the upper watershed could increase the erosive force of the river downstream, resulting in increased streambank erosion and loss of property. Large wood in the upper watershed works to sieve out wood and retain it there. Disruption of wood clusters in the upper watershed may increase the transport rate of large wood to the lower watershed to worsen logjams on bridges in the lower watershed. Leicester (2005) hypothesized that release of impounded large wood in the upper watershed may benefit fishery habitat in downstream reaches only if catcher logs were in place downstream.

The ultimate benefit of annual logjam removal was brought seriously into question by research on Soquel Creek after the January 1982 flood. Singer and Swanson (1983) found that most of the wood that jammed up on the Soquel Avenue Bridge was not in the channel when the storm began. The major source of logs during the 1982 flood was forested hillslopes that failed during the flood mainly from debris flows. By September 1983, 59 major logjams had been cleared in 30 miles of stream (Singer and Swanson, 1983). Almost all of these jams were new because watershed streams had been cleared of most logs prior to the January 1982 storm (Dave Hope, pers. comm. [In Singer and Swanson, 1983]). They concluded that increased land use and development in the upper watershed could increase the likelihood and severity of logjams and flooding hazards in Soquel Village if improperly managed. The major types of land use include residential development and timber harvesting. Logging was the major land use activity in the East Branch. Roads play a key role in debris flow initiation. Studies in the Pacific Northwest showed that logging roads increased the rates of debris flow occurrence from 25 to 340 times the natural rate (Swanston and Swanson, 1976).

A.6.4 Barriers to anadromy

Barriers to anadromy, known as *passage barriers*, range from complete obstructions to fish passage during all streamflows, to partial impediments, such as riffles that become too shallow to allow fish passage during low streamflow.

A.6.4.a Types of passage barriers

Passage barriers may be natural or artificial.

Natural passage barriers include waterfalls, bedrock chutes, logjams, large boulder fields, steep riffles, shallow riffles, and bedrock ledges. Natural barriers may be completely removed or altered by storms to allow passage.

Artificial passage barriers include unladdered dams for water storage reservoirs, water diversion dams, summer flashboard dams, weirs, bridge abutments with concrete sills, perched culverts, and instream road crossings. Figure A.24 shows a concrete apron next to a culvert that creates a passage barrier to anadromous fish during low flows.

Figure A.24. Concrete apron at the Highway 9 culvert

Alley 1994

This concrete apron presents a low flow passage problem at Waterman Gap.

Summer dams can result in elevated water temperature in the pools formed behind the dams. These pools may inundate valuable fastwater feeding habitat for juvenile steelhead.

Flashboard dams are usually regulated to prevent impoundment of water until after smolts move downstream, in the late spring. The operation of flashboard dams in the past few years was controversial. However, the belief that juveniles move upstream in the summer appears unsubstantiated and needs further study. Shapovalov and Taft (1954) Davis (1995) both found lack of movement between sites.

NMFS denied permits in the summer of 2003 for Ben Lomond Park and Boulder Creek Recreation District. These dams will not be re-permitted until fish ladders are constructed to allow upstream and downstream movement of fish in summer when the dams are in place. No other flashboard dams will be permitted in the watershed by NMFS until recovery and de-listing of the species is successful.

A.6.4.b Location of passage barriers

The lower a passage barrier is in the watershed, the larger the impact to the salmonid population. Passage barriers low in the watershed cut off more area from spawning migration. Spawning access to tributaries above the San Lorenzo River gorge and upper reaches of the watershed is critical to the survival of the steelhead population. However, several studies (Smith 1982; Alley, 2002; Alley et al., 2004a) report limited spawning availability in the lower and middle mainstem of the San Lorenzo River.

Several passage barriers have been noted in the lower San Lorenzo River gorge, running through Henry Cowell State Park. Table A.11 and Figure A.25 describe the type and location of known passage barriers occurring on the San Lorenzo River and its primary tributaries in 2002 (Alley et al., 2004a). Other barriers, still undocumented, also exist on minor tributaries near their confluence with the mainstem San Lorenzo River.

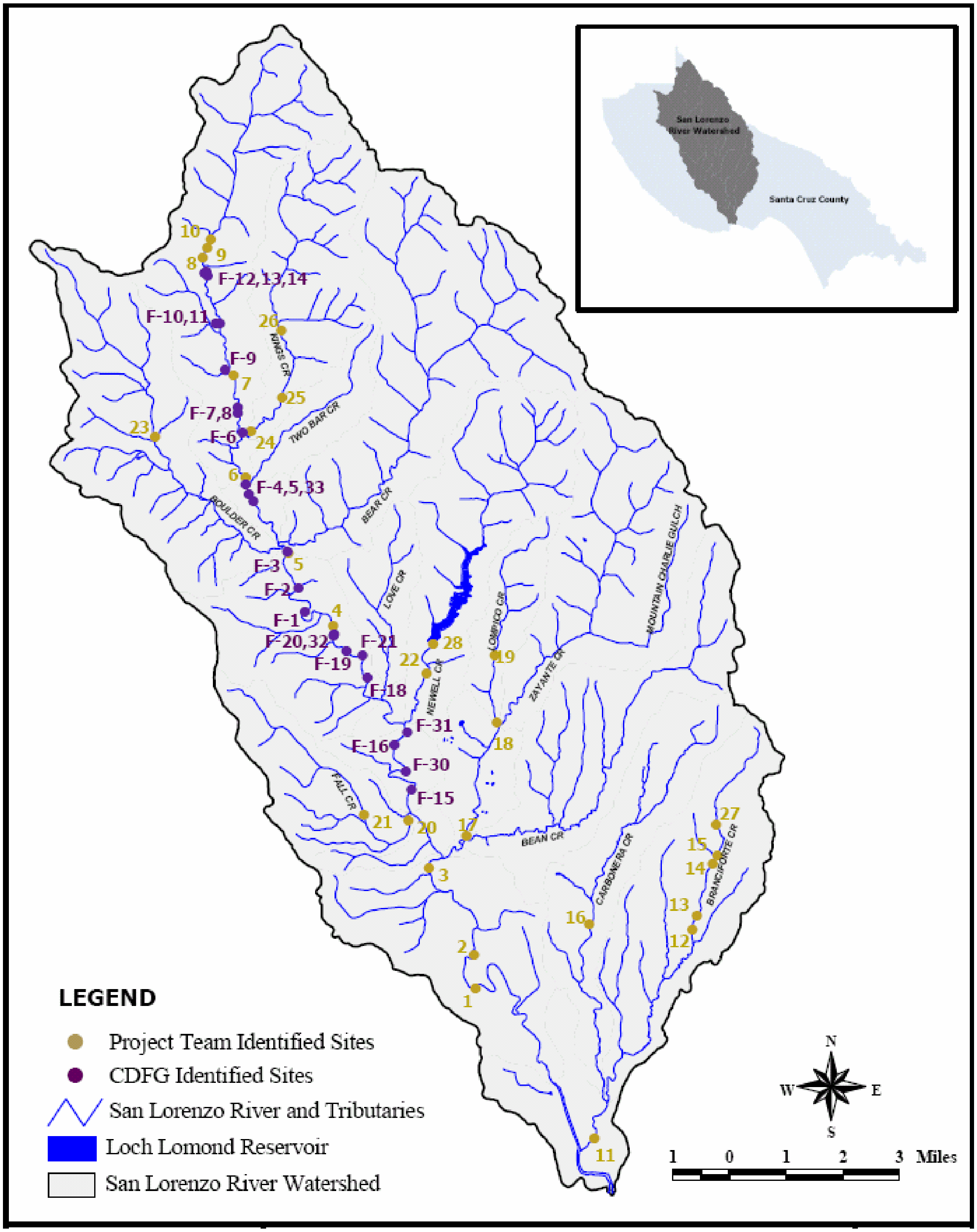
Table A.12 lists human-caused impediments in the mainstem, including potential low-flow impediments . Twenty-one of the impediments identified in this table are current or abandoned flashboard dams. Even though many of the dams were no longer in use, the abutments and concrete sills could impede adult steelhead passage during winters of low water years.

Table A.11. Description and locations of identified fish passage barriers on the San Lorenzo River and its major tributaries

ID	Location	Description	Degree of Passage Impediment
1	San Lorenzo River	Wide critical riffle in upper Rincon	Passable at ~ 70 cfs
2A	San Lorenzo River	Boulder falls above Four Rock	Passable at ~ 100-120 cfs
2B	San Lorenzo River	Boulder cluster just upstream of Four Rock	Passable at ~ 50 cfs
3	San Lorenzo River	Felton Diversion Dam	Difficulty passing at certain intermediate-flow conditions
4	San Lorenzo River	Bedrock outcrop below Brookdale	Low flow barrier
5	San Lorenzo River	Erwin Way flashboard dam apron and base	Low flow barrier
6A	San Lorenzo River	Fern Road flashboard dam apron and base	Low flow barrier
6B	San Lorenzo River	Camp Campbell flashboard dam apron and base	Low flow barrier
7	San Lorenzo River	Bedrock channel above Teilh Road	Passable at ~16.5 cfs
8	San Lorenzo River	Log jam below Waterman Gap	Low flow barrier
9	San Lorenzo River	Riprap boulder jam below Highway 9 repair downstream of Waterman Gap	Low flow barrier
10	San Lorenzo River	Highway 9 bridge apron	Low flow barrier
11	Branciforte Creek	Branciforte flood control channel	Low flow barrier. Passage depends upon maintenance schedule
12	Branciforte Creek	Concrete flashboard dam abutment	
13	Branciforte Creek	15' high Denil ladder over 10' high dam	Needs maintenance to allow passage
14	Branciforte Creek	Flashboard dam abutment with inadequate pool/weir ladder	Needs maintenance to allow passage
15	Branciforte Creek	Rock and concrete wall at Happy Valley Estates	Low flow barrier
16	Carbonera Creek	Moose Lodge Falls	Impassable at all flows
17	Zayante Creek	Flashboard dam abutment	Low flow barrier
18	Lompico Creek	Concrete wall and bedrock chute above fish ladder	Only passable at higher flows
19	Lompico Creek	Concrete floor in creek with approach apron	Low flow barrier
20	Fall Creek	Concrete weir fish ladder	Continuous maintenance required
21	Fall Creek	Boulder falls	Impassable at all flows
22	Newell Creek	Bedrock falls	Passable at ~ 200-300 cfs
	Newell Creek	Loch Lomond Dam	Complete passage barrier
23	Boulder Creek	Bedrock chute	Impassable at all flows
24	Kings Creek	Flashboard dam apron	Low flow barrier
25	Kings Creek	5 bedrock chutes and shelves	Low flow barriers
26	Kings Creek	Bedrock/boulder falls – 2 steps	Impassable at all flows
27	Branciforte Creek	Flashboard dam just downstream of Vine Hill Road	Low flow barrier
	Love Creek	Denil ladder	Needs maintenance to allow passage
	Branciforte Creek	Concrete structure below flashboard dam	Low flow barrier

Source: Alley et al. 2004.

Figure A.25. Location of identified fish passage impediments on the San Lorenzo River and its major tributaries.



Source: Alley et al., 2004a. For descriptions of each gold site refer to Table A.11.
Purple sites are those identified by CDFG and CAB on the mainstem in a survey conducted in summer 2001 (Table A.12). There may be overlap between locations.

Table A.12. Passage impediments* identified by Community Action Board staff in summer 2001 on the San Lorenzo River mainstem

Map ID	CAB ID	Description	Concern	Priority**
1	1	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
2	2	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
3	3	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
4	4	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
5	5	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
6	6	active large concrete flashboard dam	debris and geomorphic and moderate flow concerns	Highest
7	7	grouted bed associated with bank revetment	geomorphic and low flow concern	High
8	8	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
9	9	grouted bed associated with bank revetment	geomorphic and low flow concern	Highest
10	10	active large concrete flashboard dam	debris and geomorphic and low-moderate flow	highest
11	11	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
12	12	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
13	13	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
14	14	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
15	15	small grouted rock dam	low flow concern	Low
16	16	legacy concrete flashboard dam	minor debris and geomorphic and low flow concerns	Low
18	18	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	Moderate
19	19	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	High
20	20	active small grouted rock flashboard dam	minor debris and geomorphic and low flow concerns	Low
21	21N	natural bedrock slide	moderate flow concern	High
30	n/a	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	High
31	n/a	legacy concrete flashboard dam	minor debris and geomorphic and low flow concerns	Low
32	n/a	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	Low
33	5N	legacy small concrete flashboard dam	debris and geomorphic and low flow concerns	Low

Source: Alley et al., 2004a, summarizing walking surveys by CDFG and CAB.
*All manmade, channel spanning structures with potentially adverse effects on fish passage and other important watershed processes on the mainstem from Highway 1 upstream. It does not include the two City of Santa Cruz diversion facilities at Tait St. and Felton. Restoration priority was determined by CAB and CDFG personnel (and not Alley et al.) based on field estimates that considered both the feasibility of fixing the site, and the potential benefit to the fishery. No hydraulic calculations were done.

** The priority ratings for removal of these low flow impediments were not those of the enhancement plan authors (Alley et al., 2004a)

A.6.4.c Effect of streamflows on passage barriers

During the 1976-77 drought, the watershed area available to spawning was reduced by 50%, and the size of the runs was very low (Ricker and Butler, 1979). If streamflow through the San Lorenzo River gorge is low enough, it could prevent upstream salmonid migration. This situation could result from too much water being diverted from the stream at the Felton diversion dam, for human consumption. If coho or steelhead were prevented from migrating upstream through the gorge, most of the watershed would become inaccessible to spawning. Only limited spawning habitat exists below the gorge, except in the Branciforte sub-watershed.

Most of the gorge, consisting of high-gradient riffles and boulder falls, was judged passable in 1992 to adult salmonids at streamflows of 35 cfs or higher, using the criteria of 0.6 feet minimum depth across five contiguous feet of channel width (Alley, 1993). After the El Niño storms of 1997-1998, a critically wide riffle developed in the Rincon area, creating a significant passage impediment that was still present in 2002 (Alley et al., 2002).

In 1991 during a drought, adult steelhead did not reach the Felton diversion dam until the mean daily flow reached 100 cfs (Alley et al., 2004a). Although the boulder cluster above Four Rock in the gorge was presumably limiting passage in 1991, it was observed to have become favorably rearranged in 2002. However, it may remain difficult to pass at streamflows less than 50-70 cfs (Alley, personal observation). Visual observations of the Rincon area in 2001 indicated that adequate passage flows for steelhead may not be reached at flows less than 70 cfs (Alley pers. observation). Water diversion during a drought year, in combination with naturally low baseflows, may prevent adult salmonid access to the upper watershed or at least severely limit it. Mean daily streamflow was less than 50 cfs at the Big Trees Gage for most of the winter from winter 1986-87 through winter of 1990-91 (5 years) except for one to three minor storm events each winter.

Estimated average daily flow extractions in January, March, April and December may significantly reduce streamflow during drought or below average flow years, downstream of the Felton Diversion Dam in the San Lorenzo gorge. This could adversely impact adult salmonid passage during those months during a drought or below average flow years.

In the middle river, the Felton diversion dam may create passage barriers at certain streamflows. Adult salmonids may not find the fish ladder, which is intended to enable upstream migration at low and intermediate streamflows. When water is spilling over the inflated rubber dam, adult salmonids cannot jump over it except at higher stormflows (Alley et al., 2004a).

A.6.5 Poor water quality

Poor water quality is one of the principal limiting factors of salmonid survival in the San Lorenzo River watershed. Water temperature and dissolved oxygen concentration are the water quality parameters most important to salmonid survival. Water contaminants, such as fecal coliform or nitrates that are of concern for human health, are not considered threats to salmonid survival in the San Lorenzo River upstream of the lagoon.

A.6.5.a Water temperature

Water temperature influences virtually all aspects of salmonid life history. Water temperature affects metabolic rate, range of swimming ability, digestive rate, microhabitat selection, as well as competition, predator-prey relationships, and disease-host relationships. Increased water temperature increases metabolic demands and oxygen requirements of juvenile salmonids. Water temperatures generally remain below levels known to be stressful to local steelhead populations within the San Lorenzo River. Exceptions may occur during times of lowest streamflow in unshaded reaches, which are also the times of lowest levels of escape cover and food availability. Fish may starve to death if their metabolic demands from elevated water temperature exceed food supply. Hungry fish are less responsive to predators (Brown et al., 1994).

In the San Lorenzo River, as in other Central Coast streams, water temperature is probably not directly lethal. Higher temperatures, however, increase food demands and restrict steelhead to faster habitats for feeding, especially above 21º C (70º F) (Smith and Li, 1983). Critically high water temperatures reduce the scope of swimming ability for stressed juvenile steelhead and increase the risk of predation. In the warmest reaches of the lower and middle San Lorenzo River, where streamflow and food supply are highest, starvation is not a problem for steelhead. Rather, juvenile steelhead grow faster in these reaches than in cooler tributaries and the upper San Lorenzo, because the abundance of food outweighs the higher metabolic energy costs. The warmer water also speeds digestion and allows for faster assimilation of food to promote faster growth rate.

The lethal water temperature for steelhead is probably above 26-28º C (79-82º F) for several hours during the day. These temperatures are rarely, if ever, reached upstream of the lagoon (Alley et al., 2004a). Even so, warmer temperatures could result in slow growth or starvation in steelhead if food supply becomes very limited. In the upper mainstem and tributaries where streamflow is less, food supply is reduced and cooler water temperature maintains lower metabolic rates for salmonids and reduces food requirements. If shade is removed in these small streams, water temperature may rise too much, causing food requirements of the fish to increase without concomitant increase in food abundance. Cool tributary inflows to the mainstem, such as Clear Creek and Fall Creek help to maintain mainstem water temperatures within a tolerable range for juvenile steelhead inhabiting the mainstem.

Coho generally are found at cooler temperatures than steelhead. Although the lethal temperature limit for coho is similar to steelhead, coho would likely starve at water temperatures above 18-20º C (65-68ºF) in the lower and middle mainstem San Lorenzo River (Alley et al., 2004a). Alley et al. (2004a) also reports that water temperatures cooler than 21^{o} C may not be possible in the lower and middle mainstem San Lorenzo River, especially in areas with a wide stream channel and lack of riparian canopy closure despite a healthy and intact riparian corridor. Even if water temperatures lower than 18^{o} C were possible, few coho would likely survive where pools are often long (more than 200 feet in length), where long pools dominate the stream channel (70-80% of the habitat in the middle mainstem) and where food and fastwater feeding areas are in limited supply (Alley et al., 2004a).

In the Mattole River system (northern California), coho were found only in tributaries where the maximum weekly average water temperatures were 16.7ºC (62ºF) or less and the maximum weekly maximum temperatures were 18.0ºC (64ºF) or less (Welsh et al., 2001). To arrive at these temperature criteria, they determined the average daily water temperature for the weeks under consideration and determined the average maximum daily water temperature for those weeks. Then they correlated the maximum for all of the average weekly temperatures and the maximum for all of the average maximum weekly temperatures to coho presence or absence. Because of the generally sandy substrate in the San Lorenzo system, and the presence of steelhead, the temperature limits found in the Mattole River are probably the appropriate goal for re-establishing coho in the low gradient portions of tributaries in the watershed and possibly the middle mainstem in wet years. In Scott and Waddell creeks in Santa Cruz County, coho have been found at warmer sites than those in the Mattole River, but only where the pools were very productive (small pools, abundant algae, extensive, productive riffles upstream of the pools, etc.) (Smith pers. observation). Branciforte, Carbonera, Zayante, Bean and Bear creeks are potential candidates for coho habitat.

A.6.5.b Dissolved oxygen

Within the San Lorenzo River system above the lagoon, recorded levels of dissolved oxygen are well within the tolerance range of salmonid populations. Steelhead can likely survive dissolved oxygen levels as low as 2mg/l at cool, early morning water temperatures, but would need more dissolved oxygen throughout the day to sustain activity (Alley et al., 2004a). Habitats throughout the San Lorenzo River system meet the San Lorenzo River Salmonid Enhancement Plan goal of 5 mg dissolved oxygen per liter of water (Alley et al., 2004a). Water turbulence in shallow water riffles keeps oxygen levels at, or near, full saturation levels. However, as water warms, the saturation level of oxygen decreases. Cooler water contains more oxygen. Algal blooms in slack water are uncommon in the river, so that possible depressed oxygen levels at night due to eutrofication and high biological oxygen demand (BOD) are not known to occur in the stream environs of the San Lorenzo system. However, it is possible that potentially lethal depressed oxygen levels might occur in the lagoon. Critically low oxygen levels might occur if sufficient saltwater is trapped on the bottom for a long enough time to raise water temperature to critical levels during intense algal blooms. Adequate lagoon inflow during the summer will discourage this condition.

A.6.6 Other potentially limiting factors to salmonids

Hatchery fish planting, pinniped predation and freshwater sport fishing are discussed in this section, as potential limiting factors to salmonids in the San Lorenzo River watershed.

A.6.6.a Hatchery fish planting

Historically, the method that CDFG has used to increase fish populations for commercial and recreational fishing has been the planting of thousands of fish, raised artificially in hatcheries. Hatchery stocking of the San Lorenzo River often came from fish outside the Central California Evolutionary Significant Unit (ESU), from northern and interior California hatcheries. Northern California steelhead and coho salmon have a different genetic makeup that may result in habitat requirements and behavior that is not well suited to the San Lorenzo system.

It was not understood until the early 1980s that central California steelhead and coho have distinctive DNA and behavior adapted to local environmental conditions. Long-term deleterious effects upon native salmonid populations may result from the loss of genetic integrity and adaptation to special environmental challenges that natural selection had achieved. Special physiological adaptation to warmer water temperatures and timing spawning and smolting to match the rainy season may be lost from genetic exchange between native fish and fish from other geographic areas.

Competition for habitat and resources between hatchery and native stocks is of great concern to biologists trying to restore native populations. Hatchery fish were planted at rates perhaps far above the carrying capacity of the aquatic ecosystem, resulting in increased competition in the stream and the ocean and reduced survival of native stocks.

Hatchery stocks may introduce disease to already stressed and depleted natural populations. Any confined rearing situation, such as a hatchery, increases the probability of disease. It is believed that bacterial kidney disease (BKD) found in wild coho salmon was originally spread throughout North America through hatchery planting. After the Big Creek hatchery was experiencing poor egg survival in wild coho salmon stocks, it was discovered that many of the wild brood stock had BKD. As a result, adults are now injected with Erythromycin to eliminate the bacteria before egg-taking, to insure survival of offspring.

The Brookdale Hatchery opened in 1905 to enhance the sport fishery. Steelhead from the Brookdale Hatchery were planted throughout the watershed until 1953 (Cramer et. al, 1995). These planted steelhead came from eggs of Scott Creek and San Lorenzo River steelhead. The Brookdale Hatchery was closed in 1954 because it spread whirling disease to native steelhead populations (W. Evans, personal communication).

Trapping records indicate that hatchery personnel drove the many rural roads in the county, planting fish at most stream crossings. Many were planted above natural barriers where resident rainbow trout populations now exist. In essence, these resident rainbows are genetically isolated. Natural resident populations of rainbow trout resulting from native steelhead may also exist, because headwater areas that were at one time accessed naturally by anadromous steelhead have since become inaccessible.

Steelhead in the San Lorenzo watershed are probably a genetic combination of native stock and hatchery introductions from many sources (Cramer et al., 1995), including:

- Trapped Scott Creek and San Lorenzo adult stocks (plantings from one or the other source 1905-1940; 1980 - present)
- Mt. Shasta rainbow trout (pre-1930)
- Mad River steelhead (1954 -1974)
- Sacramento Valley rainbow trout (1958 - late 1970's)
- Carmel River steelhead (1984 - 85)
- Russian River steelhead (1985).

Planted coho salmon during the 1984-1994 period originated from northern stock from the Noyo River and Prairie Creek in combination with San Lorenzo stock. No coho have been stocked in the San Lorenzo since 1994, as shown in Table A.13.

Table A.13. Number of stocked juvenile steelhead and coho smolts in the San Lorenzo River mainstem, 1959-2000.

Year	Coho	Steelhead	Year	Coho	Steelhead
1959	35,800	55,000	1982	0	20,250
1961	300	1,200	1983	19,770	21,000
1963	40,169	1,396	1984	17,160	37,146
1964	40,056	0	1985	0	24,606
1965	20,330	0	1986	15,991	29,200
1967	0	11,791	1987	0	48,510
1969	25,000	0	1988	20,445	23,256
1970	25,008	29,364	1990	34,500	52,487
1971	25,008	30,000	1991	19,880	98,337
1972	20,007	40,250	1992	1,872	107,515
1973	25,005	185,795	1993	11,808	93,974
1974	25,008	0	1994	4,047	47,247
1975	25,009	50,000	1995	0	49,238
1976	25,002	36,840	1996	0	28,800
1977	0	116	1997	0	31,986
1978	0	10,070	1998	0	2,210
1979	25,011	26,070	1999	0	30,599
1980	0	10,500	2000	0	21,328
1981	0	50,040			

Source: CDFG, as cited by Alley et al., 2004a.

In recent years the Monterey Bay Salmon and Trout Project has established a native anadromous fish rearing facility on Big Creek, tributary to Scott Creek, which uses only steelhead and coho brood stock from our local ESU. The Monterey Bay Salmon and Trout Project now plants only steelhead smolts from San Lorenzo stock into the San Lorenzo River. However, if brood stock is not captured throughout the spawning migration period, then artificial selection for either early or late spawners may occur, depending on when the adults are captured for egg-taking. There is a tendency to take brood stock early in the spawning season and under-represent late spawners. Late spawning is adaptive in winters that have large late winter storms that scour out early nests. Early spawners are also more vulnerable to angling. Even if the hatchery plants come from native stocks, the most fit juveniles have not been naturally selected for in the hatchery and may lead to a loss of genetic fitness in the adults that return to spawn. Thus, the artificial selection in the hatchery may weaken genetic fitness. If small fingerlings are planted in streams to grow to smolt size, competition for limited juvenile rearing habitat may depress survival of native fish populations. For these reasons, even hatchery fish from local stocks may reduce reproductive success and their offspring may have reduced survival in the natural environment.

Although fish hatcheries may be a temporary fix for dwindling salmonid populations, they have important value. Drought, combined with water extraction and habitat degradation, have impacted native populations of steelhead to the point of near extirpation. Hatcheries are needed to re-introduce coho to watersheds where they have been lost, such as the San Lorenzo River.

A.6.6.b Pinniped predation (seals and sea-lions)

Pinniped predation of steelhead is a normal function of marine ecology. According to the Santa Cruz County Fish and Game Advisory Committee's petition to list local steelhead populations as threatened, natural predation is normally not critical to steelhead survival. But with depressed numbers of steelhead, as a result of other impacts, they believed that pinniped predation has become more significant. Some argue that because pinnipeds are a protected species, they have become overabundant. Weise and Harvey (2001) suggest that pinniped predation may be a contributing significant factor to the diminishing steelhead runs in the San Lorenzo River. They estimate that harbor seals have consumed from 3.5 to 19.8% of the steelhead runs, depending on the size of the steelhead run (Weise and Harvey, 2001). More adult spawners may be consumed by pinnipeds in years when run size is already reduced due to other environmental impacts. For example, when sandbars at rivermouths are delayed in opening because of drought and water extraction, salmonids congregate nearshore and become easier prey.

A.6.6.c Freshwater sport fishing

The San Lorenzo River has been popular with steelhead and coho salmon anglers since the early 1900's. The river is easily accessible to the San Francisco Bay area, and is the largest steelhead river south of San Francisco Bay (Benkman, 1976). Sport fishing contributed significantly to the local economy into the 1970s, when it was estimated that an average of 50,000 angler-hours per year were spent on the river. CDFG estimated that that the San Lorenzo was the fourth most fished steelhead river in California (Ricker and Butler, 1979).

Recreational fishing and fish-planting efforts to increase recreational fishing opportunities have negatively impacted the San Lorenzo steelhead population. Cramer et al. (1995) found that most of the estimated harvest rates were sufficiently high to damage steelhead populations during years when ocean and freshwater survival is low.

"Catchable trout" (actually, hatchery steelhead) were planted to supplement the recreational fishery, beginning in 1905. Historical fishing regulations lacked bag limits on salmon and trout, an indication of abundant fish populations. As fish populations dwindled due to increased fishing, bag limits were introduced, and limits steadily increased. Daily bag limits first appeared in the Fish and Game Code in 1941, when summer and winter fishing seasons were first established on California streams. After the 1976-77 drought, summer trout fishing was banned (Ernie Kinzli, Ernie's Casting Pond, pers. comm.).

For the winter fishing season, a daily bag limit of two steelhead was instituted in 1941, with fishing days restricted to Wednesdays, weekends, holidays and the first and last day of the season. This regulation remained in place until 1997 when steelhead became federally protected. The winter fishing season has remained fairly constant, beginning in either mid-November or December 1 to the end of February or 1 week into March. For a while after the federal listing, anglers were allowed to keep 1 hatchery adult per day. Current regulations require catch-and-release only, with barb-less hooks. Fishing is allowed only on the mainstem, downstream of the Lomond Street Bridge in Boulder Creek. State budget cuts have seriously affected the enforcement ability of CDFG, which was already understaffed.

Fishers have played an important role in advocating for restoration of the coho and steelhead populations. Both sport and commercial fishers historically helped to restore salmon and steelhead runs in California. The majority of members of Monterey Bay Salmon and Steelhead Trout Project are recreation-oriented fishers. This group is an important Central Coast organization, which created and now operates the Big Creek Native Anadromous Fish-Rearing Facility (Hatchery). The hatchery provides native central coast steelhead and coho smolts to supplement local runs. It also provides an important salmonid educational program to the public schools in which steelhead are raised in the classroom and released by students into local streams.

A.7 Quantitative assessment of juvenile steelhead and coho salmon populations in the San Lorenzo River

Table A.14 summarizes recent historical salmonid population estimates in the San Lorenzo River. In 1981, Smith (1982) and Alley systematically electro-fished the San Lorenzo River for juvenile coho and steelhead. An index of 1,500 adult steelhead in the mainstem was calculated for winter of 1983-84 from this sampling (Alley, 1995). Alley continued sampling of the mainstem from 1994-1997, sampling the entire watershed from 1998-2001 using a similar methodology to that of Smith (1982). In 2003-2005, they continued to sample the middle and upper mainstem (upstream of the Zayante Creek confluence) and four tributaries (Zayante, Bean, Boulder and lower Bear) in the upper watershed.

H.T. Harvey & Associates sampled the San Lorenzo system in 2002, utilizing non-random methods similar to Alley's, and a random sampling subset within the middle mainstem. H.T. Harvey & Associates did not calculate an index of adult returns for 2002. The critical factor limiting the population is the juvenile stage in freshwater. Poor habitat quality and quantity reduces juvenile numbers in freshwater. Trend analysis of the juvenile steelhead population occurred from1998 through 2001 (Alley, 2002) for the entire watershed. The mainstem was monitored in 1981 and since 1994.

The mainstem was divided into lower (Reaches 1-5), middle (Reaches 5-9) and upper (Reaches 10-12) for biological, hydrologic and geomorphic reasons, as shown in Figure A.25). Tables A.13 and A.14 show annual estimates by size class and age class.

Table A.14. Estimates and indices of returning adult steelhead and adult coho salmon to the San Lorenzo River.

Year or Winter Season	# of Steelhead	# of Coho salmon	Method	Notes	Source
1964	20,000	2,500-10,000	Creel census estimate		Johnson, 1964
1970-71	1,816	383	Creel census		Ricker and Butler 1979
1976-77	1,614 trapped	174 trapped	Count from incomplete Felton fish trapping	Dry year	Ricker and Butler 1979
1977-78	3,000	182 trapped	Incomplete steelhead seasonal estimate; Coho is a total count from Felton fish trapping		Ricker and Butler 1979
1978-79	625	100	Estimate from incomplete Felton fish trapping season	Possible effects from 1975-77 drought	Kelley and Dettman 1981
1979-80	496		Count from incomplete Felton fish trapping		Kelley and Dettman 1981
1983-84	1,500	present	Index from sampling juvenile populations in 1981	Mainstem only	Smith 1982 and D.W. Alley & Assoc.(2006)
1994-95	311	Not observed	Count from incomplete Felton fish trapping		
1996-97	1,080	Not observed	Index from sampling juvenile populations from 1994	Mainstem only	D.W. Alley & Assoc
1997-98	1,780	Not observed	Index from sampling juvenile populations from 1995	Mainstem only	D.W. Alley & Assoc
1998-99	1,540	Not observed	Index from sampling juvenile populations from 1996	Mainstem only	D.W. Alley & Assoc
1999-2000	1,300	Not observed	Index from sampling juvenile populations from 1997	Mainstem only	D.W. Alley & Assoc
2000-01	2,500	Not observed	Index from sampling juvenile populations from 1998	Watershed	D.W. Alley & Assoc
2001-02	2,650	Not observed	Index from sampling juvenile populations from 1999	Watershed	D.W. Alley & Assoc
2002-03	1,650	Not observed	Index from sampling juvenile populations from 2000	Watershed	D.W. Alley & Assoc
2003-2004	1,600 (1,007 trapped at Felton)	14 trapped	Index from sampling juvenile populations from 2001 Trap Count from incomplete Felton fish trapping season	Watershed	D.W. Alley & Assoc ----------------- SLV High trap results
2004-2005	317 trapped	18 trapped	Trap Count from incomplete Felton fish trapping		SLV High trapping results

A.7.1 Overall mainstem trend in smolt-sized juveniles, 1994-2001

The number of smolt-sized juveniles is most important in determining the expected number of adult returns. Table A.15 shows that the 1994-2001 estimates for larger, smolt-sized juveniles produced in the mainstem increased in 1995 after the drier 1994 year, followed by a steady decrease from 1995-2001. Only the lower mainstem produced more smolt-sized fish in 2001 compared to 2000, this being due to more YOY's growing into Size Class 2. In 2001, there were fewer yearlings, and YOY's grew more slowly with reduced streamflow than past years. The production of larger juveniles in 2001 was at a 5-year low for the middle river and remained low in the lower and upper River as occurred in 2000 (Alley, 2002).

A.7.2 Overall watershed trend in smolt-sized juveniles, 1998-2001

Table A.15 shows that the overall smolt population in the watershed was relatively large in 1998 (45,500), even though there were fewer yearlings. This was because there was a large YOY population with the increased habitat brought on by high streamflow, and many of those grew to smolt size in the mainstem with accelerated growth. The smolt population increased in 1999 and then declined considerably in 2000 and 2001.

Table A.15. Estimated trend in juvenile steelhead (rounded to nearest 500), by size-class, in the San Lorenzo River mainstem* for fall 1981, 1994-2001, and in San Lorenzo River tributaries for fall 1998-2001.

Year	Mainstem or Tributaries	Number of size-class 1 steelhead (< 75 mm SL)	Number of size-class 2 & 3 (smolt-sized) steelhead (=> 75 mm SL)	Total number of juveniles
1981	Mainstem	37,000**	31,500**	69,000**
1994	Mainstem	24,500	23,000	45,000
1995	Mainstem	37,000	38,000	75,000
1996	Mainstem	40,000	32,500	72,500
1997	Mainstem	63,000	25,000	88,000
1998	Mainstem	31,000	26,000	58,000
1998	Tributaries	91,500	19,000	111,000
1998	TOTAL	123,000	45,500	168,500
1999	Mainstem	17,500	24,000	41,500
1999	Tributaries	73,500	28,500	102,000
1999	TOTAL	91,000	53,000	144,000
2000	Mainstem	12,500	11,000	23,500
2000	Tributaries	59,000	19,500	78,500
2000	TOTAL	72,000	30,500	102,500
2001	Mainstem	23,500	11,500	35,000
2001	Tributaries	70,000	16,500	86,500
2001	TOTAL	93,500	28,000	121,500

*from Highway 1 to above Waterman Gap
** Prior to 1996, estimates came from sampling site densities extrapolated to reach densities. In 1997, estimates came from habitat-type densities extrapolated to reach densities after habitat proportioning was determined. A revised 1996 estimate was generated, using 1997 habitat proportions. In 1998-2001, habitat proportions were annually determined. Estimates are approximate and rounded to the nearest 500.
Source: Alley 2002.

A.7.3 Overall mainstem trend in total number of juveniles, 1996-2001

Table A.16 shows that the total numbers of juveniles from the mainstem in 2001 were less than half of 1996. Table A.16 also shows that total juvenile steelhead production for the watershed in 2001 was approximately 72% of the 1998 total (Alley, 2002).

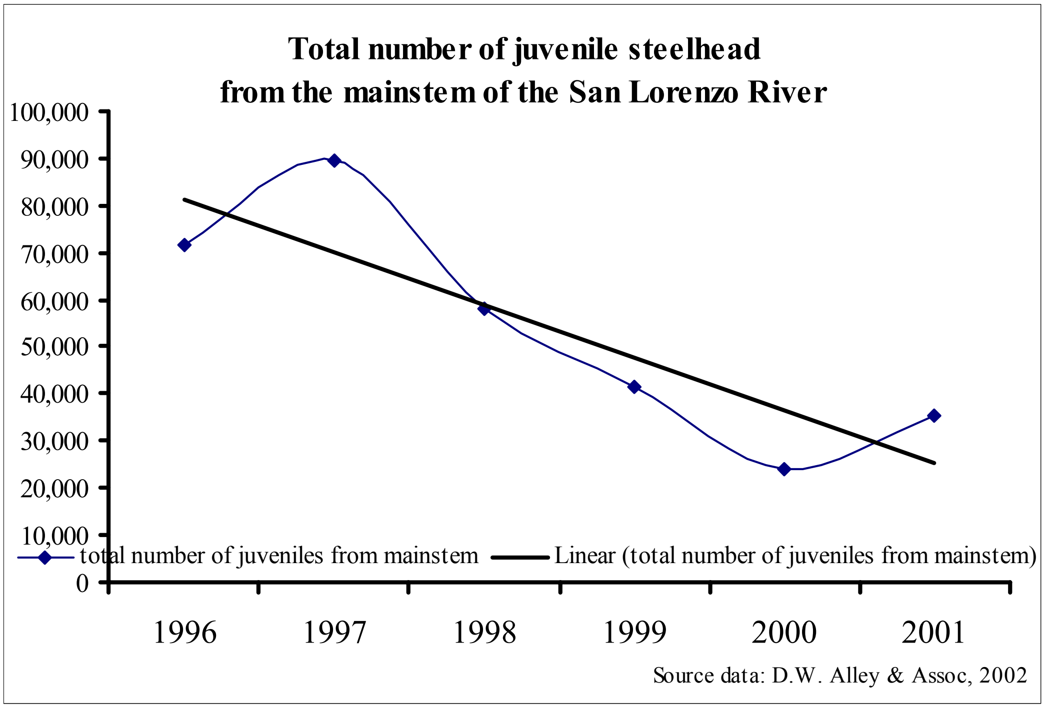
Figure A.26 shows the trend in total juvenile population in the mainstem for 1996-2001. The long-term trend is a dramatic decrease in juvenile production. The population size decreased from 1996 to 2001, with a slight increase from 1996 to 1997 and from 2000 to 2001.

Table A.16. Estimated trend of juvenile steelhead, by age-class, in the San Lorenzo River mainstem* for fall 1996-2000, and in San Lorenzo River tributaries for fall 1998-2000.

Year	Mainstem or Tributaries	Number of YOY** steelhead	Number of yearling steelhead	Total number juveniles
1996	Mainstem	62,000***	9,500***	71,500***
1997	Mainstem	81,500	8,500	89,500
1998	Mainstem	52,500	5,500	58,000
1998	Tributaries	103,500	9,500	113,000
1998	TOTAL	156,000	15,000	171,000
1999	Mainstem	34,500	7,500	41,500
1999	Tributaries	74,500	28,000	102,500
1999	TOTAL	109,000	35,000	144,000
2000	Mainstem	18,000	5,500	24,000
2000	Tributaries	61,000	17,500	78,500
2000	TOTAL	79,500	23,000	102,500
2001	Mainstem	30,500	5,000	35,500
2001	Tributaries	69,500	17,000	86,500
2001	TOTAL	100,000	22,000	122,000

* from Highway 1 to above Waterman Gap
** YOY are young-of-the-year fish
*** All estimates were rounded to the nearest 500. Estimates for all juveniles combined differed when combining age classes versus size classes, because density estimates at sampling sites were determined separately by age and size.
Source: Alley 2002.

Figure A.26. Trend in total number of juvenile steelhead per year for the mainstem San Lorenzo River from 1996-2001.



A.7.4 Overall tributary trend in yearling (smolt-sized) juveniles, 1998-2001

In the tributaries, where growth is slower than in the lower and middle mainstem, only yearlings are smolt-sized in all but the wettest years, such as 1998 and 2005. The tributary smolt (yearling) population in fall 1998 was much less than in 1999 because many of the yearlings were flushed from the watershed during the El Niño storms of winter 1997-98. Then there was a steady decline in smolt production in the tributaries from 1999-2001, with slower growth rate in 2001 due to reduced streamflow, as shown in Tables A.13 and A.14.

A.7.5 Trends in smolt-sized juveniles in the middle and upper mainstem and four upper tributaries, 1998-2005

Trends indicated by data gathered (H.T. Harvey, 2003) (Alley 2004; 2005; 2006) in the upper mainstem and four upper tributaries (Zayante, Bean, Boulder and lower Bear creeks) show how the steelhead population responded after the El Niño. In short, habitat and fish sampling results in 2005 indicated the first solid year of recovery after the negative El Niño effects and a series of drier years. These data are summarized in Table A.17.

In the middle and upper mainstem there was a general decline in smolt production from 1998 through 2002, from approximately 12,000 to 5,000 smolt-sized juveniles. The numbers remained stable during 2002-2004, and then increased to about 7,000 in 2005. This recent increase was likely the result of improved habitat conditions and higher growth rates that were stimulated by higher streamflow. There was also a significant increase in smolt densities from 2004 to 2005 at the middle mainstem sites. With higher streamflows in 2005, YOY growth rate was greater and a higher proportion of them reached smolt size than the previous year.

In the four tributaries, the smolt-sized juvenile numbers increased from approximately 9,000 in 1998 to a high of about 17,000 in 1999, followed by a steady decline in 2000-2002 to about 7,000. In 2004, low smolt production in Zayante Creek resulted from less escape cover, and low smolt production in Bean Creek resulted from more extensive dewatering of reaches of Bean Creek. In 2005, numbers increased to about 13,000, the highest since 1999. This increase resulted from improved habitat, faster growth rate of some YOY steelhead into the smolt-sized group, and perennial flow in the Bean Creek reaches associated with the higher baseflow.

The decline in yearlings and smolt-sized juveniles for all sites sampled together was statistically significant from 2003 to 2004. This decline was likely due to high winter storm events that flushed out over-wintering yearlings, followed by low baseflows in spring and summer that led to slow growth rates of YOY's. When smolt densities at all sampling sites in 2005 were compared to 2004 densities, the increase was statistically significant.

Table A.17. Estimated trend of juvenile steelhead (rounded to nearest 100), by size-class, in the San Lorenzo River middle and upper mainstem* and 4 upper tributaries (Zayante, Bean, Boulder and lower Bear) for fall 1998-2005.

Year	Partial Mainstem or 4 tributaries	Number of size-class 1 steelhead (< 75 mm SL)	Number of size-class 2 & 3 steelhead (=> 75 mm SL)	Total number of juveniles
1997	Mainstem	54,300	10,400	64,700
1998	Mainstem	28,500	12,400	40,900
1999	Mainstem	16,000	8,500	24,500
2000	Mainstem	11,400	6,500	18,000
2001	Mainstem	19,600	5,300	24,900
2002	Mainstem	51,600	4,600	56,200
2003	Mainstem	30,900	5,100	36,000
2004	Mainstem	26,700	4,800	31,600
2005	Mainstem	24,300	6,500	30,800
Average	Mainstem	29,300	7,100	36,400
1998	4 Tributaries	57,600	9,200	66,800
1999	4 Tributaries	39,700	17,200	56,900
2000	4 Tributaries	29,700	11,900	41,600
2001	4 Tributaries	38,000	9,300	47,300
2002	4 Tributaries	62,700	6,400	69,100
2003	4 Tributaries	78,900	12,300	91,200
2004	4 Tributaries	57,900	6,900	64,800
2005	4 Tributaries	57,400	13,200	70,600
Average	4 Tributaries	52,700	10,800	63,500
1998	Combined	86,100	21,600	107,700
1999	Combined	55,700	25,700	81,400
2000	Combined	41,100	128,400	59,600
2001	Combined	57,600	14,600	72,200
2002	Combined	114,300	11,000	125.300
2003	Combined	109,800	17,400	127,200
2004	Combined	84,600	11,700	96,400
2005	Combined	81,700	19,700	101,400
Average	Combined	82,000	17,900	99,900

Source: Alley, 2006.

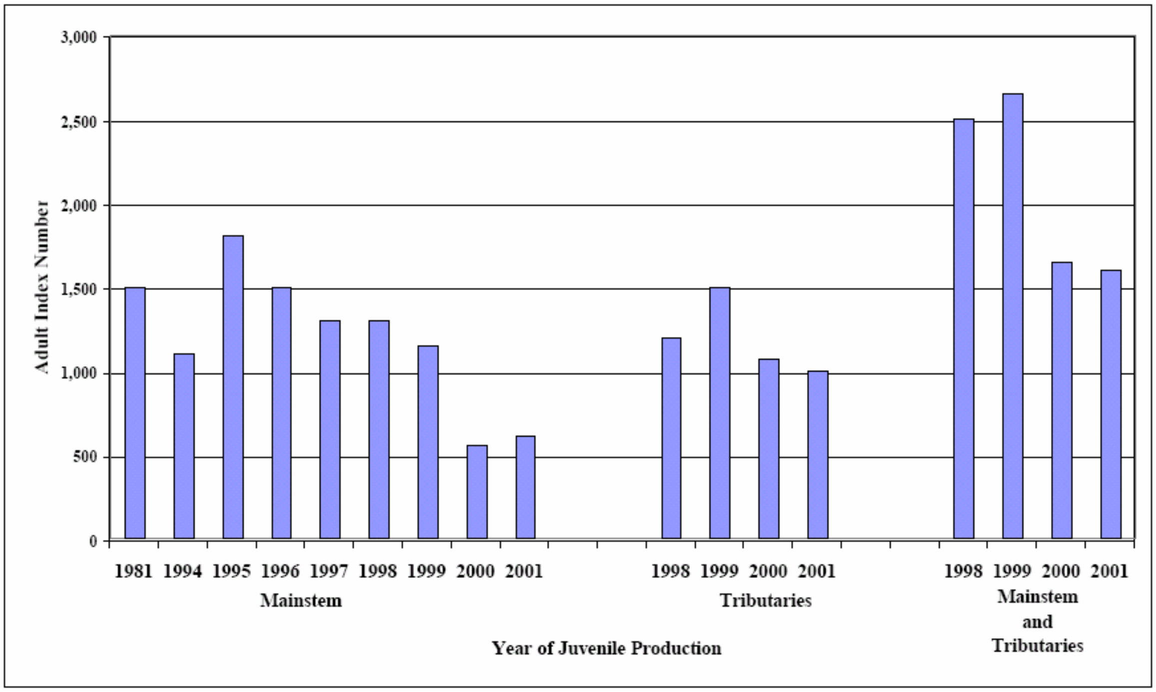
A.7.6 Trends in index of adult returns

Overall, from the 2003-2005 sampling it appears that the adult index has fluctuated since 2001 and was improving in 2005.

An index of adult returns was generated from juvenile production in each year of monitoring by D.W. ALLEY & Associates, based on the production of 3 size classes of juveniles (Alley, 2002). The most evident trend in the adult index was the precipitous decline in the mainstem contribution from 1997-2001 (Figure A.27; Table A.18). As a result, there was a steady decline in the adult index for the entire watershed for 1997-2001, with the relative tributary contribution of smolt-sized juveniles as yearlings increasing. This is indicative of habitat decline in the mainstem, resulting from severe sedimentation of rearing habitat after the El Niño winter of

1997-1998, along with apparent poor spawning success in later years and reduced baseflow through those years. Judging from monitoring of the middle and upper mainstem in 2003-2005, the adult index continued to be low with slight improvement in 2005, as habitat conditions improved (Alley, 2006). The adult index in the four tributaries that were monitored in 2003-2005 indicated a rebound in 2003 from a low in 2001, then a decline in 2004 to below the 2001 estimate, primarily because of stream dewatering in Bean Creek. Then there was a rebound in the adult index in 2005 when Bean Creek was again watered from high baseflows.

Figure A.27. Trends in the index of adult steelhead returns projected for the San Lorenzo River, based on year of juvenile production.



Source: Alley et al., 2004a.

Table A.18. Conservative index of adult steelhead returns to mainstem San Lorenzo River.

Sampling Year	Index of Returning Adults 2 Years Hence
Mainstem	
1981	1,500
1994	1,100
1995	1,800
1996	1,500
1997	1,300
1998	1,300
1999	1,150
2000	550
2001	610
Average	1,200
Middle and Upper Mainstem	
1998	650
1999	450
2000	350
2001	300
2003	350
2004	300
2005	400
Average	400
9 Tributaries	
1998	1,200
1999	1,500
2000	1,100
2001	1,000
Average	1,200
4 Tributaries	
1998	600
1999	900
2000	650
2001	550
2003	850
2004	500
2005	850
Average	700
Mainstem + 9 Tributaries	
1998	2,500
1999	2,650
2000	1,650
2001	1,600
Average	2,100
Partial Mainstem + 4 Tributaries	
1998	1,250
1999	1,350
2000	950
2001	850
2003	1,150
2004	800
2005	1,200
Average	1,100

Source: Alley et al., 2004a; Alley 2006.

A.8 Comparison of fish sampling methods.

For watershed management purposes, it is necessary to know if habitat quality is improving or not, where most YOY and smolt-sized fish are produced, and which stream reaches have the highest potential for supporting these young fish. It is also necessary to know how the juvenile population is responding to habitat changes. By sampling representative habitat of average quality, the juvenile production has been estimated with sufficient accuracy to detect trends in annual production, as well as changes in size classes and age classes in relation to habitat quality (e.g.; increased smolt-sized juveniles when escape cover and water depth increase). A comprehensive salmonid assessment and enhancement plan was developed for the San Lorenzo River, based on data collected from the D.W. ALLEY & Associates' long-term monitoring program (Alley et al., 2004a). The continuing program has included salmonid habitat surveys and measurement of juvenile steelhead abundance. Monitoring of juvenile numbers and habitat conditions, and assessing threats to all life stages, are critical to recovery of the species (NMFS, 2005).

The San Lorenzo River has been censused by D.W. Alley & Associates using a representative reach extrapolation technique (RRET), a well-established, systematic method in fishery biology. Systematic, nonrandom sampling has been commonly used in California to assess trends in fish population size. The RRET method has been used by the CDFG for years in sampling Delta smelt and striped bass to detect population trends and manage populations in the California Delta (J. Smith pers. communication). The NMFS regulatory branch supports continued sampling using this methodology (Haynes, pers. comm. NMFS Santa Rosa 2005). This method relies on professional judgment to select representative sampling sites, rather than random selection. The RRET method is useful for revealing trends in annual fish population numbers, as well as for comparing populations in different portions of the watershed. This method assumes that habitat with average habitat quality will produce approximately average densities of juvenile steelhead. Sampling of representative sites each year enables detection of trends in population size and habitat conditions. Because of the non-random nature of site selection, analysis of variance is not possible with the RRET method. Nor is it possible with this method to establish confidence intervals for juvenile population estimates. If a more statistically robust estimate of juvenile population numbers is needed, a stratified random sampling approach is required. However, the RRET method is sufficient for most watershed management purposes, and is less labor-intensive, and less expensive.

On the other hand, random sampling is currently the basis for most calculations of confidence intervals (to show that patterns seen are not due to random chance), and statistical analyses. However, random sampling does not reveal population trends over time, as does the method RRET method. A random sampling methodology capable of rigorous and robust statistical analysis is the method used by agencies such as USFWS and CDFG. NMFS fisheries laboratory also requested random sampling in 2002. The scope of random sampling necessary to encompass the entire watershed has proven expensive, however.

A random sampling approach used to census juvenile coho is the basin-wide visual estimation technique (BVET) (Hankin and Reeves, 1988; Dolloff, Hankin and Reeves, 1993). BVET uses a stratified random sampling design that allows statistical analysis of variance. It relies primarily on a visual census by snorkeling, with some calibration through electro-fishing. Data collection with BVET reduces the cost of random sampling. However, the BVET method could under-estimate juvenile densities. In heavily shaded stream reaches, where the stream channel is small and fish hide in cover, visual census is not the best approach. In pools in the upper mainstem and tributaries, where calibration between visual estimates and electro-fishing estimates may be attempted, the BVET method is more labor intensive than is necessary for monitoring of trends in juvenile salmonid numbers. Shallower riffles, runs and step-runs are too shallow to visually census, and must be electro-fished. The BVET method recommends a visual census of 25% of the pools, and for calibration, they recommend electro-fishing 10% of those pools. In the San Lorenzo River, this would result in a questionable calibration factor.

A.9 Recovery efforts for coho salmon and steelhead

The National Marine Fisheries Service began a recovery plan for the Central California Coast Coho Salmon ESU (CCC ESU) in 2005, as required by the federal ESA. The agency describes the recovery process:

> Recovery is the process in which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the federal ESA are no longer needed. A variety of actions may be necessary to achieve the goal of recovery, such as the ecological restoration of habitat or implementation of conservation measures with stakeholders (NMFS, 2004).

A priority number of "1" was assigned to the Central Coast coho salmon ESU in accordance with the agency's recovery priority guidelines (55 FR 24296, Section B). "This ranking is based on a high degree of threat, a high recovery potential and an anticipated conflict with development projects or other economic activity" (NMFS, 2005).

The recovery outline lists the following priorities to address the low effective population size and limited spatial distribution of the CCC ESU:

- Conduct and improve research and monitoring on distribution, status and trends.
- Protect and restore watersheds and estuarine habitat complexity and connectivity.
- Improve freshwater habitat quantity and quality.
- Promote and improve operations of current recovery hatcheries and develop hatchery and genetic management plans to minimize negative influences of hatcheries.
- Improve enforcement of fishery rules and regulations.

The recovery outline lists the following priorities to address the low winter and summer survival of juveniles, limited smolt production, reduced spawning success and low productivity of the Central California Coast ESU:

- Focus on freshwater habitat restoration (e.g., erosion control, bank stabilization, riparian protection and restoration and reintroduction of large woody debris).
- Improve riparian protections and habitats.
- Balance water supply and allocation with fisheries' needs through water rights programs, identification and designation of fully appropriated watersheds, development of passive diversion devices and/or off-stream storage, elimination of illegal water diversions, and improved criteria for water drafting, storage and dam operations.
- Improve agricultural, instream gravel mining and forestry practices.
- Improve county/city planning, regulations (e.g., riparian and grading ordinances) and county road maintenance programs.
- Improve state road maintenance and management.
- Remove/upgrade man-made fish passage barriers (e.g., watercourse crossings, dams and others) in high priority watersheds and stream reaches.

- Screen water diversion structures in anadromous fish bearing streams.
- Replace existing outdated septic systems and improve wastewater management.
- Promote concept of multi-use/recycling of water to increase water supply (e.g., use of tertiary treated wastewater for golf courses and other appropriate uses).
- Identify and treat point and non-point source pollution to streams from wastewater, agricultural practices and urban environments.
- Modify channel and flood control maintenance practices, where appropriate, to increase stream and riparian complexity.
- Eliminate artificial breaching of sandbars for improvements in channel and estuarine habitats.
- Improve understanding of life-state survival at the sub-population scale through focused research and monitoring.
- Provide outreach to Federal action agencies regarding section 7(a)(1) and the carrying out of programs that conserve and recover Federally listed salmonids.
- Encourage enforcement, improved performance and needed revision to pertinent state and local rules and regulations such as Forest Practice Rules, urban storm water permits and others.

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APPENDIX B: HISTORY OF LOGGING REGULATION IN SANTA CRUZ COUNTY

Commercial logging throughout the state remained unregulated until 1937, when San Mateo County adopted the first timber harvest ordinance in the state (Arvola, 1976). In 1945, the State enacted the original Forest Practice Act, which pre-empted county regulations (Arvola, 1976). The act gave sole authority to regulate to the California Department of Forestry and Fire Protection (CDF) and the state Board of Forestry.

In 1971, the state Forest Practice Act was ruled unconstitutional by the State Supreme Court (*Bayside v. San Mateo County*), because the majority of seats on Board of Forestry were allotted to the timber industry, creating a situation of self-regulation by the industry. According to the Public Law Research Institute (PLRI, 2006):

> Under the 1945 Act's self-regulatory system, private timber owners had exclusive authority to promulgate rules governing forest practices, with few mechanisms to ensure protection of the environment. The court held that by delegating such broad legislative power to persons with a pecuniary interest in logging, the Act violated the state and federal Constitutions and [d]enied due process of law to the interested and affected public.

The outcome of this 1971 decision was that state regulation under the Forest Practice Act was suspended. During that time, Santa Cruz County adopted a county ordinance to regulate logging. Under the county's authority, timber harvest applications were subject to review under CEQA. Applications involved public hearings, and the County Board of Supervisors could order changes in timber plans to address public concerns. The county had authority to require sureties to ensure compliance with county rules.

In 1973, the Z'Berg-Nejedly Forest Practice Act (FPA) was enacted by the state legislature, re-establishing the authority of state to regulate timber harvest. For a complete treatise on the FPA, refer to Duggan and Mueller (2005). The FPA re-created the Board of Forestry with a majority of "public seats." The FPA did not pre-empt county authority to regulate timber harvest within their jurisdictions, so from 1973- 1982 commercial logging was regulated by both the California Department of Forestry and Fire Protection (CDF) (now known as CalFire) under the California Forest Practice Rules (CalFire Forest Practice, 2007) & the county.

In 1976, the state legislature enacted the Forest Taxation Reform Act, which "changed the method of taxing timber in California by replacing the ad valorem tax on standing timber with a yield tax on harvested timber. The resulting *timber yield tax* is imposed on every timber owner who harvests timber or causes it to be harvested on or after April 1, 1977" (California Board of Equalization, 2007).

In 1982, the state legislature enacted the Timber Productivity Act (California Government Code Section 51100-51104), zoning 5.4 million acres of land throughout state, for timber production (TP) and compatible uses. The state required counties to assess each parcel based on its ability to grow trees. All qualifying lands were required to be zoned to TP, unless the landowner could show why another zoning would be more appropriate.

In 1983, the state legislature pre-empted the counties' authority to regulate timber harvest (Senate Bill 856). Since then, counties were required to gain approval from Board of Forestry for special rules to apply within their jurisdictions, but which could be enforced only by CDF.

During the 1990s, logging operations throughout the state increased after the state Board of Forestry introduced a new type of operation into the Forest Practice Rules. These operations required no environmental review, and so were called "exemptions." A state commission investigating the problem found:

> The number of emergency notices and exemptions totaled slightly more than 1,500 in 1989. By 1993, the number had skyrocketed to more than 8,000: 1,100 emergency notices and 6,959 exemptions. This far outstripped the 1,206 regular Timber Harvest Plans submitted for approval in 1993" (Little Hoover Commission, 1994).

Logging under exemptions proliferated in residential areas throughout Santa Cruz County, including the San Lorenzo River watershed (Santa Cruz County Planning Department, 1998, 1999). Conflicts increased over issues such as road damage by logging trucks, threats to public health and safety, nuisance, and lack of local control.

In addition, large out-of-county timber owners, who had depleted their timber land holdings on the North Coast, had been buying up thousands of acres of forest land in Santa Cruz County. In the 1990s, these timber companies began to log these lands intensively throughout the county. The County documented environmental damage and examples of inadequate enforcement by CDF with respect to some of the timber harvest plans in its justification packet for the County's proposed 1998 and 1999 rule changes to the Board of Forestry (Santa Cruz County, 1998, 1999).

Also in the 1990s, local environmental groups began focusing on the impacts of logging on drinking water. Local water suppliers were publicly criticized for commercially logging their water-supply forest land. In 1995, Citizens for Responsible Forest Management, a local non-profit, sued the City of Watsonville, contesting the city's plan to log the heart of the city's watershed, known as Grizzly Flat. While the group ultimately lost in court, they publicized the impacts of logging on water quality, through an effective media campaign.

In 1999, about 50 citizens complained to the Santa Cruz City Council about the city's continued logging of its watershed lands and the resulting impacts on water quality. The City Council responded by placing a moratorium on any further logging, appointing a task force to address the issue, and by providing $250,000 in funding for the preparation of a watershed management plan. The task force oversaw a team of consultants, which wrote the watershed management plan for the city's 3,880 acre holdings around Newell Creek, Laguna Creek, and Zayante Creek. In 2002, the Planning Analysis and Recommendations Report for the watershed was completed. The overall recommendation, to meet the city's primary goal of preserving water quality and quantity for protection of health and safety, was to limit land uses to those that improve water quality and restore ecosystem function. More specific recommendations included an end to the city's commercial logging program, since it contributed to erosion, and was counterproductive to ecosystem restoration (Swanson Hydrology and Geomorphology, 2002; Herbert, 2004).

In November 2002, the Santa Cruz City Council unanimously approved a motion to end commercial logging on the city-owned watershed lands and adopt other task force recommendations to protect and improve water quality (Santa Cruz City Council, 2002).

In 1998, Santa Cruz County Board of Supervisors submitted a county rule package prepared by the county planning department (Santa Cruz County Planning Department, 1998) to the Board of Forestry, proposing protection of old-growth trees, no-cut zones around streams, improved road construction standards, and allowing county planners to visit timber harvest operations. All of the proposed substantive changes were rejected by the Board of Forestry, after the local timber industry lobbied against the rules (Herbert, 2004).

In 1999 the county board of supervisors prohibited commercial logging in most zones outside of TP, removing approximately 22,000 acres from potential use as timber. However, any property owner wishing to rezone to TP could do so by simply filing an application, as long the property exceeded the county-designated 5 acre minimum parcel size and was capable of growing timber.

Shortly thereafter, in 2000, Big Creek Lumber sued the County of Santa Cruz, (Big Creek Lumber Co. v. County of Santa Cruz) challenging, among other things, the County's authority to prohibit logging outside the TP zone. The timber company argued that only the state had the authority to regulate the conduct of logging operations. The County argued that zoning authority gave counties the power to limit the location of land use activities to certain zone districts. The issue worked its way through Santa Cruz County Superior Court, the Sixth District Court of Appeals, and eventually to the State Supreme Court, which ruled in the county's favor in 2006.

In May 2007, the County Board of Supervisors changed the minimum parcel size eligible for rezoning to TP to 40 acres, but allowed for exceptions with discretionary review. The board also approved a six month grace period that allowed landowners wishing to rezone to TP under the old standard of a 5 acre minimum parcel size (Santa Cruz County Board of Supervisors, 2007).

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To: Watershed Plan Reviewer/Contributor

From: Betsy Herbert, Ph.D.
Environmental Analyst
San Lorenzo Valley Water District

Date: October 26, 2009

Re: Errata Sheet for Part I: Existing Conditions Report

Below is an "Errata Sheet" for the final version of the San Lorenzo Valley Water District Watershed Management Plan, Part I: Existing Conditions Report, which was published on May 11, 2009.

Please remove and recycle page xx, entitled "Acknowledgments," from your document, and replace it with the enclosed revised pages xx and xxi.

Also, please add the enclosed one-page inserts, also entitled "Acknowledgements," to the end of Chapters 1-7 and Appendices A and B.

Thank you.

ERRATA SHEET

The San Lorenzo Valley Water District has corrected the original "Acknowledgments" section of the District's Watershed Management Plan, Part I: Existing Conditions Report. The original "Acknowledgments" section did not list the titles and affiliations of the document's contributors and reviewers.

Accordingly, readers should replace page xx, "Acknowledgments," dated 5/11/09 with the enclosed pages xx and xxi, dated 10/20/09.

In addition, readers should add the enclosed one-page inserts, also entitled "Acknowledgments," and dated 10/20/09, to the end of each respective chapter and appendix.

The District has made these same revisions to the on-line document on the District website:
http://www.slvwd.com/watershed.htm